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PAPERS IN PRESS FOR FORTHCOMING ISSUES

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LOW-VELOCITY LAYERS IN THE EARTH'S MANTLE. By B. Gutenberg

Secretary's Note: Reprints of the two correlation charts in this issue will be available *after* April 1. Remittance should accompany order.

CORRELATION OF THE ORDOVICIAN FORMATIONS OF NORTH AMERICA. By Ordovician Subcommittee W. H. Twenhofel, *Chairman* *50 cents*

CORRELATION OF THE CRETACEOUS FORMATIONS OF GREENLAND AND ALASKA. By Ralph W. Imlay and John B. Reeside, Jr. *35 cents*

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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GEOLOGIC PROBLEMS IN THE SOUTHEAST MISSOURI LEAD DISTRICT

BY E. L. OHLE AND J. S. BROWN, *Editors*[1]

ABSTRACT

This paper is essentially a progress report on the geological study being made in the Southeast Missouri District by the St. Joseph Lead Company. The problems encountered are described and the progress toward their solution is assessed. These problems have consisted of the subdivision of the Bonneterre formation into units that are mappable underground, the recognition of the types of rock alteration accompanying or preceding ore deposition, the recognition of the structural controls of the ore trends, and the collection of data that may indicate the method of ore genesis.

The Bonneterre formation is divided into eight principal zones which are numbered from top to bottom. Contacts between zones are mapped, and structural features are indicated by contouring. Ore in each zone has distinctive characteristics.

Buried Precambrian igneous knobs have localized some ore bodies in the Lead Belt area, but sedimentary arch structures of depositional origin are the outstanding features controlling ore trends. Fracture zones exerted a secondary influence where arches are present and, where arches are absent, were, in some places the dominant ore-controlling structures.

Major alteration effects are dolomitization of limestone, "fingering" and spotting, recrystallization, and removal by solution. Glauconite and adularia have been introduced or redistributed.

Lateral migration of the ore solution was important, and the vertical component of motion almost surely was up rather than down. The marginal position of sphalerite in the galena ore bodies is in accord with the relative solubilities of the two sulfides.

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[1] Principal contributions by J. S. Brown, W. S. Detrick, J. A. Emery, J. E. Jewell, J. E. Kiser, E. L. Ohle, F. G. Snyder, R. E. Wagner, W. W. Weigel, and F. B. Whiting. Written and edited by E. L. Ohle and J. S. Brown.

Introduction

For nearly 100 years the great disseminated lead district of Southeast Missouri has supplied 25 to 50 per cent of the primary lead mined annually in the United States. Its total output through 1951 has exceeded 8,000,000 tons of pig lead valued at more than $1,000,000,000. The producing area is nearly 60 miles long by 6 miles wide and is known locally as the Lead Belt. (Fig. 1). More than 90 per cent of the production has come from a triangle with sides some 7 miles in length embracing the towns of Bonne Terre, Desloge, Leadwood, and Flat River.

Despite its great productivity, this area has not until recently received the systematic geological study accorded most other mining districts as accepted operating routine. Broad-scale studies, mostly unpublished, have been made from time to time by the various companies active in the area and by independent students of ore deposition, but all of them either concentrated on specific problems or were handicapped by having limited access to the mines. These limitations are reflected in published articles on the district, most of which emphasize one or another idea as to the origin of the deposits rather than the details of stratigraphic and structural control. The standard reference on the district is still the 1908 report of Buckley, which was written when the great Flat River and Leadwood ore bodies were just undergoing development.

The lack of applied geology in Southeast Missouri is due largely to the ease of exploration by diamond drilling, for ore reserves could be maintained simply by drilling more holes in known mineralized areas. Probably more diamond drilling has been done in the Lead Belt than in any other area of comparable size in the world.

In 1947 the St. Joseph Lead Company instituted an intensive geological study of its properties under the direction of John S. Brown, Chief Geologist, who was transferred at that time from other operations. Since then, from 5 to 10 full-time geologists and several geological-engineering assistants have been engaged in underground mapping and the correlation of underground and drill-hole data. This initial phase of the program is about 75 per cent completed, and this paper is essentially an interim report describing the problems encountered and indicating the degree of progress toward their solution.

Acknowledgments

The authors are indebted to the St. Joseph Lead Company for permission to publish this report.

The Problems

1. *Subdivision of the Bonneterre[2] Formation*

The bulk of the lead ore in Southeast Missouri occurs in the Upper Cambrian Bonneterre dolomite. Its general relations are indicated in Figure 2. Much of the work of subdividing the Bonneterre had been completed by R. E. Wagner and J. E. Jewell prior to 1947 as an accompaniment of the extensive diamond-drilling program. Through a careful study of the cores from thousands of holes, starting about 1936, the rock types were classified, and the formation was divided into zones. Subsequent underground observation has clarified the relationships between certain rock types and has revealed lateral gradations which could not be detected in cores from vertical holes spaced 100 feet or more apart, but the essential features of the stratigraphic column remain unchanged.

The subdivision of the Bonneterre has been complicated by variations in the thickness and appearance of the rock types in the lower half of the formation as originally deposited, and by alteration effects which, in many places, partially or completely obliterate the original character of the beds. Although the total thickness of the formation is 375–400 feet nearly everywhere in the main productive area, lensing and some interlayering of rock types is characteristic of the lower 200 feet. Thinning of one zone is compensated by thickening of other zones to maintain the uniform total. In the upper half of the Bonneterre the sequence and thickness of rock types is much more uniform, and the bedding is more regular.

[2] The spelling Bonneterre refers to the Upper Cambrian rock formation, while Bonne Terre refers to the town of Bonne Terre, Missouri.

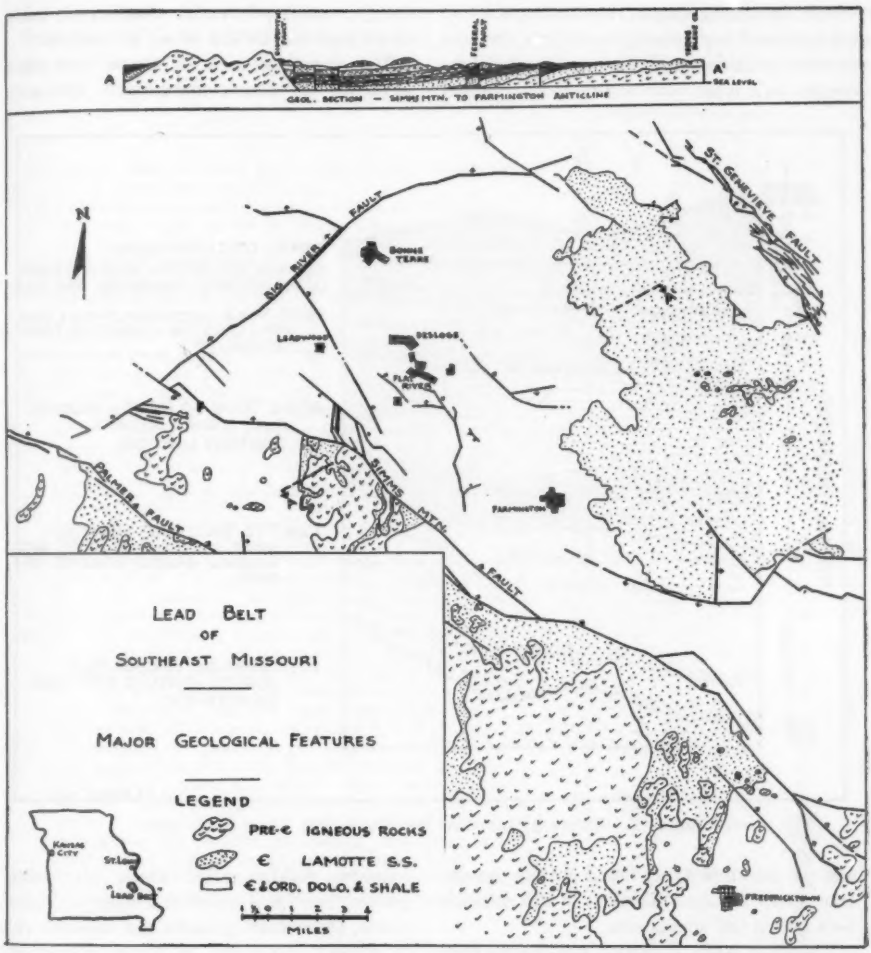

FIGURE 1.—MAP OF THE LEAD BELT OF SOUTHEAST MISSOURI

It is not always possible to determine whether a given rock type is an alteration product or a feature of original sedimentation. Complete agreement is yet to be reached as to the origin of several important types. Certain ones, such as the coarse-grained, glauconitic, light-gray rock near the bottom of the section, seem to have a dual origin, being in some places original and elsewhere secondary.

The formation is divided into eight principal units numbered from top to bottom, 1, 3, 5, 7, 10, 12, 15, and 19 (Fig. 3). The 1-bed is just below the overlying Davis formation, and the 19-bed is the sandy dolomitic phase immediately overlying the Lamotte sandstone. All these units usually are identifiable in ore-bearing areas. However, the distinctive features of several of the zones seem to result from rock alteration—possibly in part hydrothermal and associated with ore deposition. At any rate, outside the general mineralized areas these particular units have not been identified. Several of the units vary in thickness and to some extent in lithology from place to place

within the mining district, but the sequence of types is found in practically every hole. Omitted numbers in the numerical system are used for certain rock types with restricted distribution

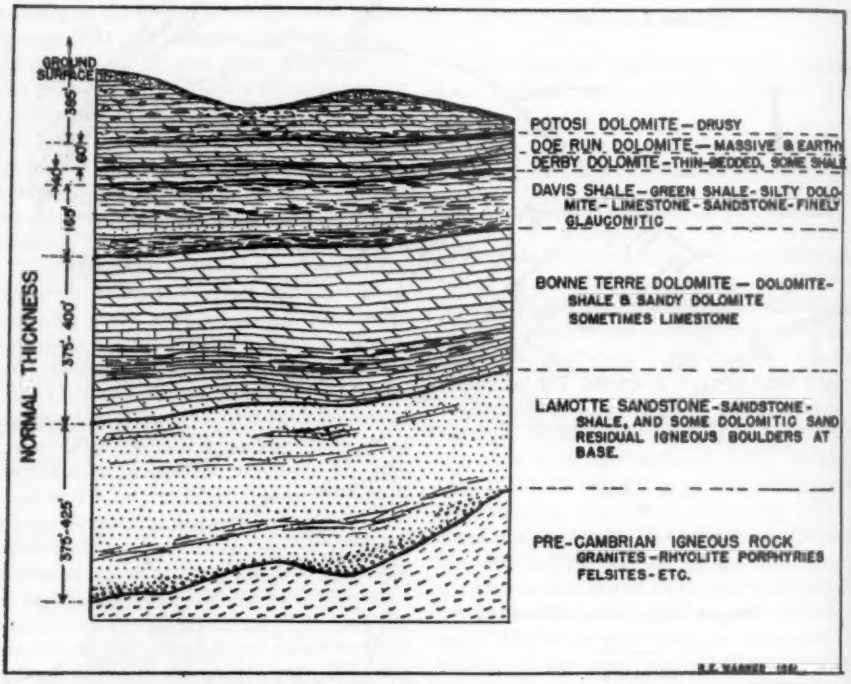
GROUND SURFACE
NORMAL THICKNESS
365'
60'
40'
165'
375'-400'
375'-425'
POTOSI DOLOMITE — DRUSY
DOE RUN DOLOMITE — MASSIVE & EARTHY
DERBY DOLOMITE — THIN-BEDDED, SOME SHALE
DAVIS SHALE — GREEN SHALE - SILTY DOLOMITE - LIMESTONE - SANDSTONE - FINELY GLAUCONITIC
BONNE TERRE DOLOMITE — DOLOMITE-SHALE & SANDY DOLOMITE SOMETIMES LIMESTONE
LAMOTTE SANDSTONE - SANDSTONE - SHALE, AND SOME DOLOMITIC SAND RESIDUAL IGNEOUS BOULDERS AT BASE.
PRE-CAMBRIAN IGNEOUS ROCK GRANITES - RHYOLITE PORPHYRIES FELSITES - ETC.

FIGURE 2.—GENERAL GEOLOGIC SECTION IN THE LEAD BELT AREA

and for limestone types found outside the district which are the equivalent of the dolomite beds within the mining area.

The 19 or sandy transition zone ranges from zero to 100 feet in thickness and from 5 to 80 per cent in sand content. Most commonly it is tan sandy dolomite but it may be gray or even green if it contains much glauconite. Its distribution is discussed in detail under Structure. The sand grains are chiefly well-rounded quartz, and typical sandstone cross-bedding characterizes the more sandy phases. The lower contact of the 19 with the Lamotte usually is sharp, but in areas where the "transition" is most sandy, the contact may be difficult to determine. The upper contact is usually distinct also, except where the overlying 15 has a few sand grains and the sand in the 19 is sparse. A further complication exists where both the 15 and 19 are glauconitic.

The 15-zone consists of several rock types including (1) dense, fine-grained, light-gray dolomite, locally called slime, (2) coarse-grained, light-gray dolomite usually with glauconite, (3) medium granular tan dolomite with or without glauconite, (4) brown-spotted, so-called "marble" beds, (5) black shale, and (6) green shale. Any or all of these may be present in a given section, but phases (2) and (3) predominate. In certain areas the 15 tends to be thickest where the 19 is thin, and vice versa. Some of the coarse-grained, light-colored, glauconitic rock seems to have essentially its original appearance, as a similar type is found where the carbonate is limestone rather than dolomite. Certain cross-cutting relationships, however, strongly suggest that 15 can result from alteration of 12-zone "crepe" rock. Spotted "marble" beds are common at the top and bottom contacts of the 15 as well as within

this zone. Some interesting relationships of these "marble" beds to black shale bands and ore are discussed under Alteration.

(1) At Flat River, a dense, gray, "dead-looking" dolomite; no ore. Some ore at Bonne Terre.
(3) At Flat River, a mottled mixture of blue and white areas with many vugs; no ore. At Bonne Terre, similar to 5 rock but chocolate brown. May carry ore in disseminated form or in thin solid streaks.
(5) Thick-bedded tan dolomite, in many places oölitic; ore spreads laterally parallel to the bedding. Most ore is at the bottom contact. Mined extensively on upper levels at Flat River and Bonne Terre, usually breaks well and gives a good roof. Ore is disseminated or in thin solid streaks. Some high-level zinc ore at Desloge.
(7) "Fingered" rock, "snurly" rock, and gray-spotted rock are characteristic. Wavy, irregular bedding, especially where "fingered". Ore spotty and not parallel to beds except at top and bottom contacts. Ore often in well-defined "roll structures" with long, straight trends of considerable vertical height. Large tonnage producer at Flat River and Bonne Terre. Some interbedded tan layers. Green shale and slime bed 35 feet above base in some areas. Occasionally contains limestone.
(10) Fine-grained, tan, and sugary or coarse crystalline and green spotted. Thickest development on southwest side of district. Underlies "tan ridge" structures. Often interbedded with 10 feet ± of 7 rock.
(12) Usually thin-bedded, fine-grained, gray dolomite with "crepe" structure. Good ore chiefly in 1–10-foot spotted "marble" bed at base. This "marble" may be "fingered" and may pass laterally into black shale plus ore. Ore spreads parallel to beds over large areas. An important zinc horizon. Often contains limestone.
(15) Characteristically coarse crystalline, and light-colored with green glauconite spots. May also contain tan dolomite, "slime", green and black shale, and spotted "marble" beds. Thin-bedded. Especially good ore rock when it contains "marble" and black shale bands. Widespread ore parallel to bedding. Especially well developed at Desloge, Leadwood, and Bonne Terre.
(19) Tan or gray dolomite with 5–80 per cent sand grains. Not generally a good ore zone. Underlies "sand-ridge" structures.

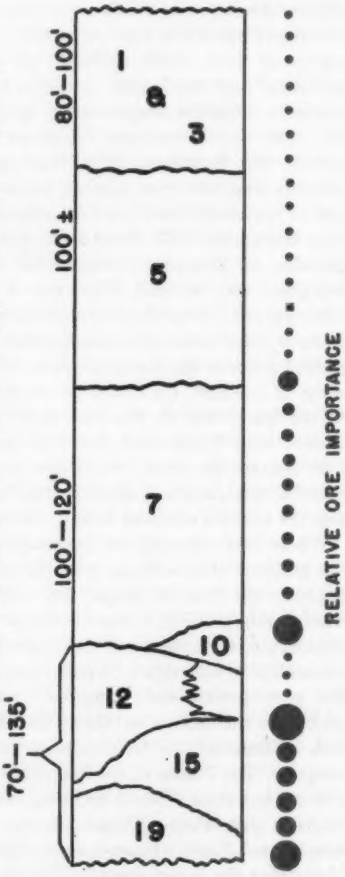

FIGURE 3.—GENERALIZED STRATIGRAPHIC SUBDIVISION OF THE BONNETERRE FORMATION
Showing the principal rock types and the thicknesses of the various zones. The size of the black spots indicates the relative ore productivity of the several zones and zonal contacts.

The 12-zone consists primarily of gray, fine-grained, thin-bedded dolomite with closely spaced paper-thin shale partings. This rock has been called "crepe" because, in cross sections, the thin wavy bedding somewhat resembles crepe paper. Tan dolomite zones a few feet thick are not uncommon and, in the area southwest of Pim shaft, all of the 12 is fine-grained, tan dolomite. Generally over the district, however, "crepe" is characteristic of 12. It may show well-developed gray spotting and brown spotting. The thickness of 12 varies considerably and is greatest in areas of least alteration. Where the structures and mineralization are strongest, the underlying, coarse-grained rock of the 15 breaks upward across the bedding and in extreme cases occupies all of the zone from the "sandy transition" to the base of the 7. In such places no 12 rock is logged. The 12-zone in many places is undolomitized limestone even in quite close proximity to ore.

The 10-zone consists of two rock types: a fine-grained, sugary-tan, occasionally oölitic dolomite and a coarse-grained, green-spotted tan dolomite. The fine-grained tan has its greatest development on the southwest side of the district where it is a part of a thick, uniform section of such rocks between the "sandy transition" and the 7-zone. It is also found in northeast-elongated tongues which give rise to the 7/10 arch structures described in the section on Structure. The coarse-grained, green-spotted, tan type is much like some 15-rock in appearance and in relationship to overlying fine-grained beds. Some of the green spots probably are glauconite; others seem to be a pale-green clay mineral. This type of 10-rock also occurs in 7/10 arch structures where it may in many places be an alteration product of fine-grained rocks of the 7 and 12 zones. Where all of the 12 is altered, the 10 and 15 are in contact. At the top of the 10, tan rock may be interlayered with 7-type rock for 5–10 feet. The 7/10 contact lies from 70–135 feet above the Lamotte sand, and over much of the Flat River area the interval is almost exactly 100 feet.

Where little altered, the 7-zone consists of fine-grained, thin-bedded, gray dolomite resembling the 12-zone "crepe" but with somewhat thicker bedding. In the vicinity of mineralization, alteration has given rise to a variegated assemblage of rock types. Of particular note are the gray-spotted and "fingered" rocks described in the section on Alteration. Where 7-rock is "fingered", the bedding is contorted and irregular. The 7-zone in the Flat River area is 100–200 feet thick. The top and bottom contacts are both quite sharp although the thin zone of interlayered 7 and 10 causes some difficulty in identifying the lower contact. The top of the highest "fingering" is usually taken as the 5–7 contact, and over a large area this lies 200–210 feet above the Lamotte. Where there is no "fingering" the contact is put at the base of the thick-bedded, oölitic tan section of the 5. In nonmineralized sections where there are no "fingers" and no 10-rock, separation of the 7 and 12 zones is not always easy. At Bonne Terre and in parts of the Desloge and Leadwood areas a 10–12 foot zone of fine-grained, gray dolomite and green shale about 135 feet above the Lamotte is a very useful marker. All the "fingered" rock in these areas lies below this zone except where the alteration has been very intense.

The 5-zone, which extends for about 100 feet above the top of the 7 consists of massive, even-bedded, tan dolomite. Much of the zone is oölitic, and especially the bottom 20 feet. The beds range in thickness from a few inches to several feet. Individual beds are constant in thickness and lithology, and in this respect the 5 contrasts sharply with the lensing and waviness found in lower zones. Many of the 5-zone beds are highly porous.

The character of the rock in the 3-zone varies according to the location in the district. At Bonne Terre 3 is similar to 5 except for a dark chocolate-brown color, which is characteristic of mineralized areas, and a lack of oölites. At Flat River and on the southwest side of the district, the 3 is a mottled mixture of dark-blue and light-gray, almost white areas with large, drusy vugs very abundantly distributed in the lighter-colored portions. In both places the zone is 80–100 feet thick. Knowledge of the blue-white rock comes entirely from drill cores as no commerical mineralization has been found in this zone at Flat River. At Bonne Terre, on the other hand, considerable ore in the uppermost levels is in the chocolate-brown type of 3. Blue-white rock is increasingly more abundant in the 3 section toward the southwest side of the district.

The "1-zone" consists of 10–15 feet of dull, gray-white, dense dolomite. Its upper contact is with the shaley, glauconitic bottom bed of the Davis formation. No ore is now mined in "1", but cog lead is found near the Davis-Bonneterre contact and attracted some interest in the early days at Leadwood and Flat River. This zone thins to the northwest and thickens to the southeast of Flat River.

All of the eight major zones are mineralized at various places although ore in the upper 150 feet of the formation is essentially restricted to the area around the town of Bonne Terre. Much of the best ore has been produced from the 7-10, the 12-15, and the 15-19 contacts, and contouring of these contacts has indicated the structures controlling many of the ore bodies. The relative ore importance of the different units and contacts is indicated in Figure 3.

The mineralization in each zone has certain characteristics, knowledge of which assists in the evaluation of drill holes and the development of ore bodies. For example, ore at any of the three contacts mentioned above tends to spread laterally parallel to the bedding for long distances and is remarkably consistent. The stopes average less than 20 feet high, and in many instances a rich mineralized streak only 2 or 3 feet thick spreads for hundreds of feet. In contrast, ore within the 7 zone is largely controlled by narrow, vertical structures and usually is more unevenly distributed than in other zones. Hence many of the stopes mined in this part of the formation tend to be long and narrow and often are several times higher than they are wide. Many trace and even blank holes have been mined out since there was good ore all around them. Whereas elevations of ore interesections at the bedded contacts are highly reliable as indicators of the level of mineralization, the elevations shown by holes in the 7-zone often are simply chance intersections with narrow, vertical lenses of ore and cannot be accepted with the same degree of confidence. Proper planning of developments for the latter type of ore body requires much more study of geological information, and clean mining is achieved only by close day-to-day observation of the ore and its controlling structures.

2. *Rock Alteration*

General discussion.—Several types of rock alteration have changed the composition and appearance of the rocks in the Bonneterre in mineralized areas. Some phases of the process definitely preceded ore introduction, while others may have been simultaneous with it. In some cases alteration may have continued after lead deposition ceased.

As previously noted, there is as yet no complete agreement as to just which rock features are primary and which are secondary. It is generally believed, however, that originally the Bonneterre formation was much more homogeneous than it is today. The middle third had many oölitic beds, and the lower half was somewhat thinner-bedded, more sandy, and more argillaceous than the rest, but there probably was not as much variation in the lithology as we now find. The widely different rock types which are the basis for the divisions in Figure 3 are in considerable part results of the alteration process. Much more study remains to be done on the complex alteration in Lead Belt rocks, but the following description indicates the general nature of the process.

Dolomitization.—Much, if not all, of the Bonneterre was originally limestone, and an early phase of alteration, quite possibly the first, was dolomitization. This definitely preceded lead introduction, but it is perhaps debatable whether the dolomitization is a direct link in the chain of ore-solution alteration, a regional diagenetic process, or both. In any event, the ore solutions made use of the physical (and chemical ?) advantages of the dolomite such as increased grain size, porosity, and permeability, for no ore whatsoever is found in limestone.

Most students of ore deposits regard the dolomitization as a hydrothermal alteration process, and there are many spatial relationships of dolomite and ore which support this view. However, great areas of dolomite contain no ore so that it is useful as a prospecting guide only in a very general way. Further, there are many cubic miles of dolomite throughout the Ozark region, particularly in formations younger than the Bonneterre, and it taxes the imagination to regard all this dolomite as hydrothermal. Possibly there are two as yet undifferentiated types and ages of dolomite in the area, one regional and diagenetic and the other hydrothermal and more restricted.

Dolomitization of the Bonneterre follows a general pattern. First, the uppermost 200 feet of the formation is porous dolomite over many square miles and far beyond any mineralization. The dolomite does give way to limestone in places, but this is by far the most persistent dolomite unit in the section. The next underlying 100 feet, on the other hand, has most strongly resisted dolomitization and is found unaltered in closest proximity to the mines as fine-grained, wavy-bedded, shaly limestone. Indeed, wedges, lenses, and islands of unaltered limestone occur in this part of the section over, around, and between ore bodies in the heart of the Flat River area.

The lower 100 feet of the formation is dolo-

mitized quite widely. Laterally from the mineralized area this lower dolomite thins rather rapidly so that drill holes within a few miles of the Lead Belt may cut only a few feet of dolomite just above the Lamotte sand. The sandy transition beds are always dolomitized.

The pattern of dolomite distribution in the middle Bonneterre beds within the Lead Belt is so closely related to the pattern of other features regarded as alteration phenomena that it is easily regarded as an ore related phenomenon itself. For example, over most of the Bonne Terre, Desloge, and Leadwood areas, there is an almost continuous blanket of limestone in the middle of the formation. In the dolomite beneath this limestone the ore spreads laterally for long distances. Locally, however, this blanket of limestone is interrupted by areas where the formation is entirely dolomitized. Such chimneys of dolomitization, which locally are termed "break-throughs", are also chimneys of other types of alteration such as "fingering", and many are chimneys of ore. That is not to imply that the dolomitized rock is all mineable but simply that ore in the upper three-fourths of the formation is entirely restricted to such dolomitized channelways and their vicinity. No ore is found above the middle limestone except near "break-throughs". "Break-throughs" seem to occur generally either in highly fractured areas or above strong arches in the 12-15 contact or over domal structures related to buried igneous knobs.

The dolomite halo is narrow at Bonne Terre, and limestone is occasionally encountered in development drifts which happen to be at the proper elevation. At Flat River, on the other hand, the dolomitization spreads for thousands of feet beyond the stoping limit, and only remnant islands of limestone remain. In the latter area, dolomitization obviously is not a very precise guide to ore; literally hundreds of blank holes have been drilled in which the rock was all dolomite.

Spotting and "fingering".—Subsequent to dolomitization, certain rocks in the 7 and 12 zones were subjected to further alteration which gave them a gray-spotted appearance (Pl. 1). Most of the spots are simply gray rings surrounding an undarkened interior. The average size is perhaps 2 mm. Some spots are spherical; others are highly irregular. The spherical ones probably inherit their shape from oölites; irregular ones may have grown unevenly around some nucleus although the nuclei are rarely observed. Still others are relict shell fragments.

When examined in thin section, the dark material in the spots proves to be fine-grained impurity in the carbonate. In some spots it quite definitely is iron sulfide; in others it appears to be clay but is too finely divided for positive identification. The iron sulfide probably was introduced by the altering solution; whether the clay mineral is an alteration product or just an original impurity of the rock made more apparent by alteration is not known.

At Flat River, gray-spotted rock is widespread and therefore is not a particularly reliable guide to ore. The halo of spotting is somewhat narrower than that of dolomitization,

---

PLATE 1.—GRAY SPOTTED AND "FINGERED" ROCK

FIGURE 1.—GRAY SPOTTED ROCK

FIGURE 2.—FINGERED ROCK

The vertical columnar structures are stained various shades of red or brown. They tend to be rounded or circular in cross section and are thus pipelike. The rock between the fingers is gray spotted. Color bands within the fingers always arch upward. The ruler is 6 inches long.

PLATE 2.—FINGERED ROCK IN VERTICAL AND HORIZONTAL SECTION

FIGURE 1.—FINGERED BEDS IN A STOPE WALL

The tan bed at the bottom of the photograph is 1 foot thick.

FIGURE 2.—CROSS-SECTIONAL VIEW OF FINGERED ROCK SEEN ON A STOPE "BACK"

The color bands are various shades of red and brown. This is locally termed "snurly rock." The individual concentric structures here average about 5 inches in diameter.

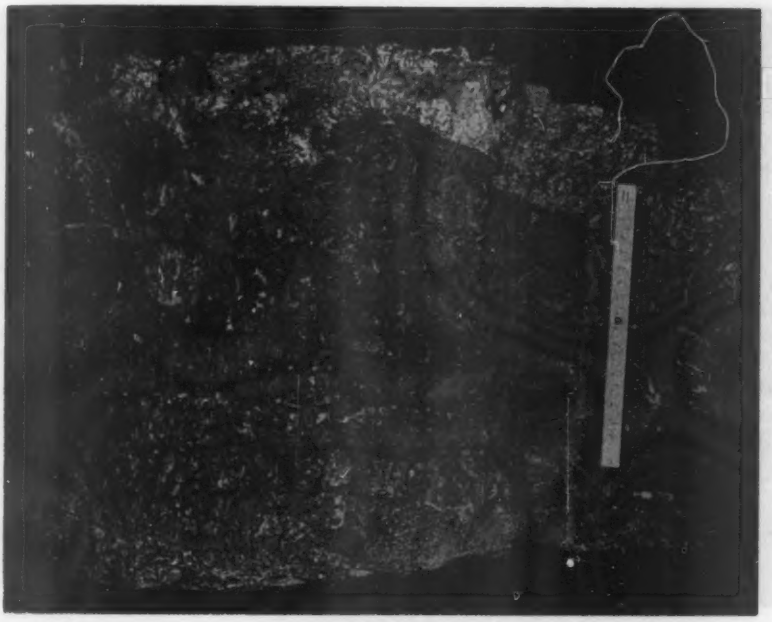

FIGURE 2

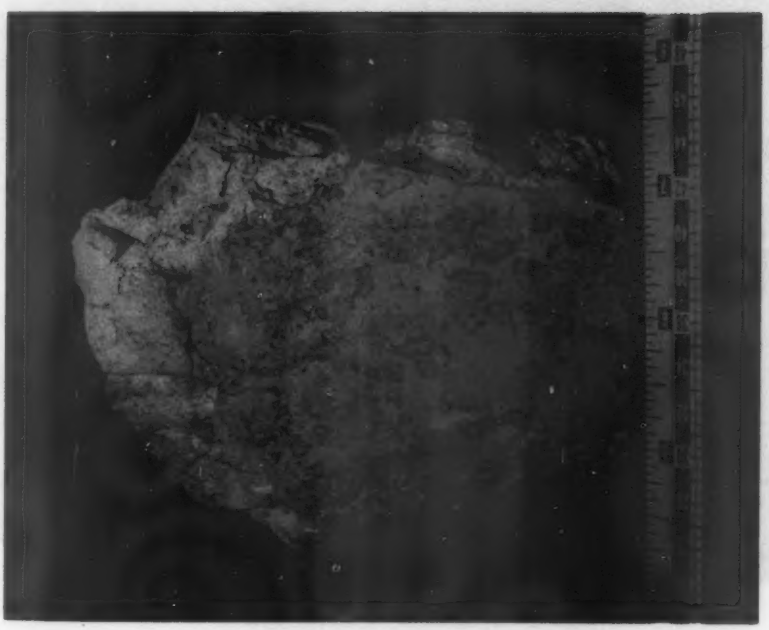

FIGURE 1

GRAY SPOTTED AND FINGERED ROCK

FIGURE 1

FIGURE 2

FINGERED ROCK IN VERTICAL AND HORIZONTAL SECTION

FIGURE 1

FIGURE 2

FAN AND HOURGLASS STRUCTURES

"ROLL" STRUCTURE IN NO. 9 FEDERAL MINE

but a few examples of gray-spotted limestone have been found, indicating that locally this second phase of alteration spread beyond the limit of the dolomitization. Here again, as in the case of dolomitization, it is not entirely clear that gray spotting is part of the chain of alteration effects brought about by the ore solution. It may be a pre-ore phenomenon unrelated genetically to the ore-solution alteration.

Subsequent to the development of gray-spotted rock, solutions moved through the formation locally causing quite striking changes in the appearance of certain layers and particularly of gray-spotted beds. An unusual alteration type known as "fingered rock" was produced by the "new" solution (Pls. 1, 2). This alteration is characterized by the development of brown stained streaks and areas through the gray-spotted beds with the gray spots being obliterated by the staining operation. Much of the staining is highly irregular in pattern, but there is a remarkable tendency to develop crude tubular or icicle-shaped structures, and to these the name "fingers" is applied. The irregular areas are included in the general name "fingered rock". Well-developed fingers tend to stand nearly vertically and thus are approximately at right angles to the bedding. They are more or less round in cross section as seen on the back of a stope and range from less than an inch to about a foot in diameter. The interior is concentrically color-banded in various shades of reddish brown, and a dark shaley film separates the fingers from adjoining unfingered rock. In vertical section, the color bands are always convex upward. The fingers mark the channelways which this phase of the ore solution used in moving through the beds, and a main point of contention is whether the tubular channelways were created during the passage of this phase of the solution or were pre-existing structures simply utilized for flow and stained in the process. Considerable difficulty arises in trying to explain the shape of fingers either as sedimentary or as secondary phenomena.

Fingering is pre-ore. It occurs in certain fine-grained beds in the formation and is especially well developed in the 7-zone and in a few beds in the 12 and 15 zones. Apparently the staining wipes out the gray spots by oxidation and transfer of the iron sulfide and redistribution of the clay material, with the oxidation of the iron presumably causing the brown coloration. Where a given bed is fingered it looks tremendously different from the way it looks when non-fingered. Not only are certain areas stained, but also the original bedding planes are distorted as though they had been squeezed and plastically deformed. A locally descriptive term for highly fingered rock is "snurly rock" in reference to the contorted appearance. This contortion definitely is not due to squeezing.

Fingering may spread laterally for long dis-

PLATE 3.—FAN AND HOURGLASS STRUCTURES

FIGURE 1.—WELL-DEVELOPED "FAN" STRUCTURE IN THE BAKER MINE

The well-mineralized, 6-inch, black shale band passes laterally into a 3-foot bed of brown spotted dolomite "marble." The sandy transition contact is at the floor on the right.

FIGURE 2.—"HOURGLASS" AT THE 12/15 CONTACT IN THE PIM-SOUTH MINE

This structural type really is a "double fan" with brown spotted "marble" beds several feet thick on each side passing into a thinner shaly band with galena and calcite in the center. The light-colored 15-rock below the structure humps up under the shale, and the crepy 12 beds above the marble slump downward, thus giving an hourglass cross section.

PLATE 4.—"ROLL" STRUCTURE IN NO. 9 FEDERAL MINE

Looking northwest at a "brow" above a mine heading. Note the great contrast in bedding thickness and attitude within and outside the "roll." The arched rocks are fingered; the thin-bedded, flat-lying exterior rocks are gray spotted and not fingered. A ¼" ± shaly band lies at the interface. On the gray-spotted side of this near-vertical interface there is a 2–3-foot zone of intense sheeting with narrow galena veinlets filling many of the fractures. The best disseminated mineralization also occurs near this interface. The rounded contour in the back of the heading has given rise to the name "roll." The shovel is 6 feet long.

tances beyond the ore as it does at Flat River, or it may be closely confined to the areas above arch structures and in "break-throughs". In many places it is associated with fractured zones. In the latter case, it occurs in the northwest-trending zones known as "rolls" (*see* section on Structure), which are important in localizing ore in Flat River mines. Fingering is rare but does occur in the 12-zone or in fine-grained rocks in the 5-zone, and it is occasionally found in the Davis and Derby-Doerun formations. However, it is best and most widely developed in the 7-zone. Detailed study of the fingering process should contribute to the knowledge of the chemistry of the ore solutions. Insofar as is known, this type of alteration is unique to the Southeast Missouri District. For a more detailed description of finger-rock, reference should be made to Tarr (1936, p. 719–721) and to Ohle (1951, p. 903–904).

Much ore occurs in erratically distributed bunches in brown altered rock. In partially altered (fingered) rock the lead prefers the margins of fingers and especially the interface between fingered and non-fingered rock. There is much fingered rock containing no lead, but the halo of fingering is more tightly drawn around "pay" ore than the haloes of dolomitization or gray spotting. Even so, occasional examples of fingered limestone are found. The quite close association of fingered rock and ore makes it likely that the brown stains are caused by a phase of the mineralizing solution. If dolomitization and gray spotting are also ore-solution effects, then fingering is simply the next step after gray spotting in a sequence of events leading up to lead introduction. In this event, the switch from "spotting" to fingering represents a striking change in the character of the solution from a reducing phase precipitating marcasite to an oxidizing phase altering marcasite to limonite.

Recrystallization.—The final and most intense phase of alteration was a recrystallization with marked increase in grain size. In most places the recrystallized rock is flecked with a greenish mineral most of which is glauconite but some of which is another clay mineral of the illite group. Such recrystallization especially affects the beds just above the sandy transition and those at the base of the 7-zone. Development of the coarse grain wipes out brown spots in basal 12 "marble" and erases all evidence of fingering except the wavy bedding.

Over most of the Leadwood and Desloge areas, where the ore is spread out beneath a limestone blanket, there is no upper coarse crystalline rock between the 7 and 12 rock types. At Flat River, however, the upper zone (10) is found in most places, and there are thus two coarse zones separated by fine-grained 12 rock. Where alteration is most intense, as over the crests of strong arch structures, the entire rock section from the top of the transition (19) to the base of the 7 (75–100 feet) may be coarse-grained, and no 12-type rock remains.

It is not believed that all of the coarse-grained rock in the 10 and 15 zones is the result of recrystallization. Much of it may be original —*i.e.*, pre-alteration, but no criterion has yet been found for separating the two types. Coarse-grained, glauconitic, undolomitized limestone has been found by drilling in a few places on the fringe of the mining district, and this quite probably is original. Within the stopes however, certain crosscutting relationships in which 15-rock sharply transects the bedding of 12 "crepe" seem difficult to explain as original sedimentary features. Also the localities where all of the 12-zone position is occupied by 15-rock invariably also show complete dolomitization of the Bonneterre and intense fingering in overlying 7-zone beds. Such bits of evidence suggest that the thickness and coarseness of the 10 and 15 zones indicate the intensity of alteration.

Contacts between an overlying dark, fine-grained rock and a lower coarse, light-colored rock, such as the 7–10 and 12–15 contacts, are highly favorable for ore as indicated in Figure 3. In such situations, the richest ore is usually in the lower few feet of the dark bed. This relationship suggests that recrystallization was generally complete before the lead phase of the solution began to circulate because the dark-light contact is the "front" of the alteration attack.

Solution effects.—In the lower part of the formation there are many irregular layers and bands of black shale, usually with a considerable proportion of included carbonate. In most cases they are rudely parallel to the bedding but

in places they transect it. Their thickness ranges from paper-thin to as much as a foot. These black shale bands are especially important in localizing ore deposition, as massive layers of galena commonly replace the dolomite immediately above and, to a lesser extent, below the shale. Much lead also occurs disseminated within the shale.

At the sides of such ore bodies and particularly on the "downhill" side of ore bodies lying along the flanks of sand ridges, the shale passes laterally into several feet of spotted, nonshaly dolomite. These features have been termed "fan structures" (Pl. 3). It has been argued forcefully that these shales bands, like stylolites supposedly, are the insoluble residues from the solution of the dolomite layers during or shortly preceding ore deposition—perhaps as an accompaniment of the recrystallization process. The explanation of the black shale as a residue does not completely satisfy the evidence, however, as the amount of insoluble seems far too high in some instances and too erratic in distribution. It is quite probable that the general structural features of the "fans" were produced during sedimentation and that later solvent action simply accentuated a pre-existing structure.

Related to fan structures is another type of feature, to which the name "hour glass" has been applied (Pl. 3), in which a shale pocket lies between downsagging beds above and uphumped beds below. The underlying material may be either sandy transition or coarse 15-rock, while the downsagged beds usually are 12 crepe or "marble". Both the hour glass and the fan resemble structures described by Grogan (1949, p. 608–613) in the Southern Illinois fluorspar district and there attributed to dissolution by the ore fluid.

The solvent power of a pre-galena solution in the Lead Belt is also indicated by the presence of numerous vugs, caves, and "hollow fingers" containing galena crystals.

The general problem of shale-band origin is being intensively studied by a research student and will be the subject of a paper illuminating in more detail this particular problem (D. F. Beaumont, unpublished thesis).

Glauconite and adularia.—Two potash-bearing minerals of particular interest have been identified in the Bonneterre rocks. Glauconite is present in the 10, 15, and 19 zones and occasionally constitutes over half of the rock volume in beds a few feet thick. Much of the green spotting described above is glauconite; some is another clay mineral of the illite group.

Glauconite is a common constituent of Cambrian rocks in the Mississippi Valley and is generally regarded as a primary mineral. Certain features of the occurrence in the mines suggest, however, that at least part of the glauconite here is secondary or at any rate has been secondarily redistributed.

The other potash mineral is adularia, which was first identified in insoluble residues and later found in thin sections. It seems to occur in all rock types, even including limestone, and is abundant in the black shale bands. Nothing is known quantitatively as to its distribution. It may be authigenic or it may be an alteration product. The fact that adularia is common in epithermal veins makes its occurrence here of more than passing interest. The distribution of both these potash minerals and the significance of their occurrence need further investigation.

3. *Structural Controls of the Ore Bodies*

Regional structure.—The broad structural features of the Lead Belt area have been described by Tarr (1936, p. 716–717) and more recently by James (1952, p. 650–651). The fundamental regional structure is the Ozark Dome, an elevated portion of the Precambrian basement dating back to Upper Cambrian time when the sedimentary formations were deposited circumferentially around a core of granite and porphyry mountains. By the end of the Paleozoic, the igneous summits had been buried to a depth probably not exceeding 5000 feet. Subsequent erosion has removed all but traces of formations younger than Lower Ordovician from the central Ozark region.

Northwest-trending faults with displacements up to 600 feet have modified the northeast side of the Ozark Dome, and, in the main lead-producing area, the original northeast dip of the sediments was reversed by the Simms Mountain fault movement so that the rocks now dip gently southwest (Fig. 1). Several northwest-trending faults with displacements

of 100 feet or less and a considerable number of northeast-trending faults with displacements of 10 feet or less cross the mineralized area. Most of them are pre-ore, but post-ore movement has occurred on some of them. The influence of these "major" faults on the detailed pattern of mineralization in the main producing area usually is slight, but locally they seem to have restricted or guided ore deposition. They do, of course, have a considerable effect on mechanized mining operations as the changes in elevation require extra development. Insofar as the regional setting is concerned, no other area has been found in the Ozarks in which the exact Lead Belt combination of structure and stratigraphy is duplicated.

The controlling influence of three principal types of structure can be demonstrated in Lead Belt ore bodies:

(1) Domal or anticlinal structures related to buried Precambrian knobs and ridges
(2) Sedimentary arch structures of depositional origin
(3) Fracture zones

Buried knobs and ridges.—The influence of buried knobs and ridges on certain ore bodies in the district has long been recognized, and descriptions of the structure are given by Tarr (1936, p. 740–741) and by James (1949. p. 654–657). This structural type is the principal ore control in the Fredericktown area, 20 miles southeast of Flat River, and three areas contain good examples within the main Lead Belt. These are in the Federal No. 8 or Mitchell Mine, the Leadwood Mine, and the Bonne Terre Mine.

In brief, the structure is the result of the progressive burial of a mature Precambrian topography by upper Cambrian sediments, starting with the Lamotte sandstone. The beds have initial dips in all directions away from the Precambrian highs. Many of the higher topographic features were not covered by the Lamotte but were subsequently buried by the overlapping Bonneterre and younger formations as shown in Figure 4. The line along which the Lamotte sand wedges out is called the "sand pinch-out", and the Bonneterre formation above this line is highly favorable for prospecting as indicated on James' map of the Fredericktown area. The "circle-run" ore bodies of the Southeast Missouri District are results of this type of control.

Seemingly the knob structures acted as traps to concentrate the flow of the ore fluid which moved upward—and laterally—through the Lamotte until that formation pinched out, whereupon it entered the overlying Bonneterre formation. The Bonneterre was favorable for precipitation, and the galena ore bodies formed there.

Although the importance of knob structures was well known before this program of geological study began, many interesting facts are being added to the knowledge of them such as the peculiar occurrences of ore in coarse conglomerate around a knob at Hayden Creek (Ohle, 1952).

Sedimentary depositional arches.—The importance of northeast ore trends in the Bonne Terre-Desloge-Flat River area is immediately apparent from the district map (Fig. 5). Well over half the district's production has been from ore bodies with northeast-southwest elongation. Perhaps the outstanding result of the underground mapping program has been the recognition that these trends are related to arch structures of sedimentary depositional origin. These structures are readily apparent on contour maps of the various contacts or on isopach maps.

At the end of Lamotte time, the sea floor over much of the Lead Belt was relatively flat. During the deposition of the lower half of the Bonneterre formation this monotony was relieved by northeast-moving currents which built ridges or bars of limy sediments which were highest on the southwest and gradually died out to the northeast. The exact reason for the location of the bars is not known although several of the most prominent examples tail out on the lee (northeast) side of Precambrian knobs which were islands in the sea at the time. The source of the limy sediment likewise is not entirely clear. A considerable part was clastic shell material from marine organisms. Much of the rest was limy ooze of uncertain origin. Currents would, of course, influence the sites of deposition of the clastic fragments, but just why the distribution of the limy ooze should be affected is not so obvious. Answers to these problems may be more apparent when the en-

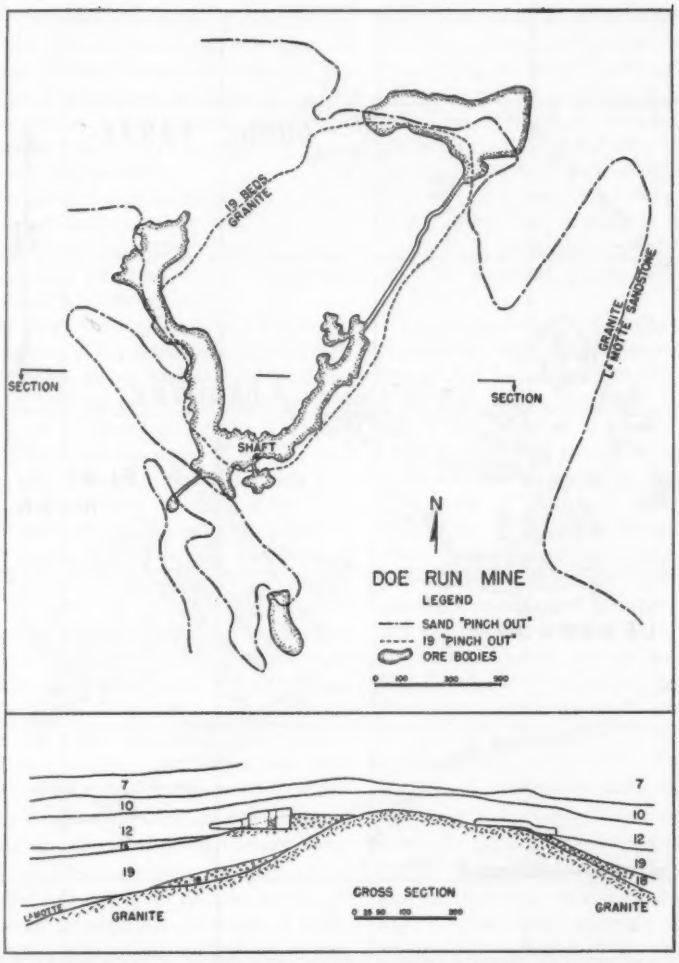

FIGURE 4.—MAP AND SECTION OF A TYPICAL GRANITE KNOB STRUCTURE

Showing the spatial relations of the ore bodies and the "pinch-out" of the sandy formation at the Doe Run No. 12 Mine.

tire district has been mapped and the pattern of ridge axes is completely known.

Ridge building in the Bonneterre formation began during sandy transition time when the 19 beds were deposited. The sandy transition dolomite ridges are better developed and known in more detail than those in the higher rocks. Figure 6 is a contour map of these ridges in the Desloge area, and Figure 7 is an isopach map of the sandy transition zone. On the southwest edge of the map, the sandy dolomite is more than 50 feet thick; to the northeast, the ridges become indistinct as the sandy layer thins to less than 5 feet. To the northeast, also, the sand grains are finer and less numerous. The interior of the ridges is cross-bedded asymmetrically. Movement on the Simms Mountain fault long after the sediments were deposited, but probably pre-ore, has reversed the plunge of the ridge axes which now are inclined 1–2° SW.

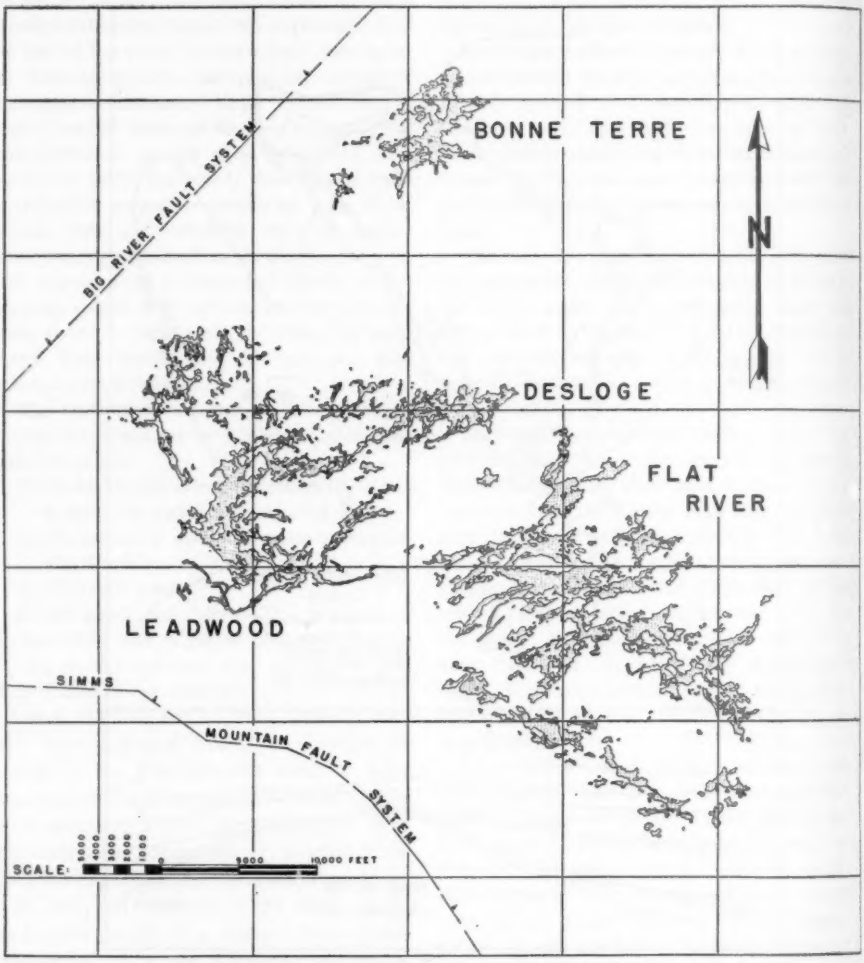

FIGURE 5.—MAP OF THE MINE WORKINGS IN THE LEAD BELT

Note the predominant northeast elongation of most of the ore trends, which were controlled by "ridge" structures. Many of the less numerous northwest-trending ore bodies were guided by fracturing and "roll structures".

This reversal is believed to have influenced subsequently the direction of ore-solution movement.

Ore related to sand ridges generally is in the 15-rock above the sandy transition dolomite (Fig. 8). The 15 beds were deposited in arch and trough structures because of having to drape over the corrugated sea-bottom topography that existed at the end of sandy transition time. The ore bodies favor the flanks of the sandy ridges and, as shown in Figures 6 and 7, it is not uncommon to have two essentially parallel ore bodies extending along the opposite sides of a ridge.

Dips in the 15 beds along the flanks frequently exceed 10°, quite steep for a district where the regional dip is only 1–2°. Most of the ore bodies accordingly have a high and a low

side. In such cases, the up-hill wall is usually coarsely crystalline and highly altered in contrast to the down-hill wall which is fine-grained and "dead looking". Some ore bodies at the 15-19 contact extend over the ridge axes as well as on the flanks. "Twelve-fifteen" contact ore associated with sand ridges is especially likely to be in the axial position.

Deposition of 15-zone sediments was thickest in the trough areas between sand ridges and tends to hide the underlying structures. Many good sand-ridge structures are not reflected in rocks 50 feet higher in the section.

Similar ridge building in certain areas continued as beds in the Bonneterre above the 19 were laid down, and depositional arches at the 12-15 and 7-10 contacts are of importance in localizing ore in these higher rocks. These are due to differential deposition of 15-rock and 10-rock. Like the sandy transition ridges they usually trend northeast. The axes of the 12-15 and 7-10 ridges do not immediately overlie the sandy transition axes; they may cross them at various angles or, as in several areas, they may show a tendency to be displaced slightly to the southeast as successively younger sediments were deposited. Figure 9 illustrates this feature which may be a result of a prevailing cross current or a gradual shifting of currents. Cross-bedding within the ridges usually accentuates the structure in the contact itself, and there actually may be arches of cross-bedding within the major structures. If these are well developed and persistent, they seem to exert an important influence on the ore similar to the influence of the main 12-15 and 7-10 contact arches. In short, domal or anticlinal structures of whatever origin, which would tend to cause convergence and concentration of upward-moving fluids have proved to be worthy of close examination and prospecting. This is the most important type of structural control in the main Flat River-Leadwood-Bonne Terre portion of the Southeast Missouri District.

Stopes mined 100 feet or more high always are at least in part in the 7-zone, and arches in the 7-10 contact had a most important role in localizing these areas of high mineralization. Figure 10 shows how one such area at Flat River is related to an axial line. An interesting feature of this type of structural control is that, although the area as a whole is elongated northeastward parallel to the underlying ridge axis, the rich ore streaks within that area are guided by fractures and have a northwest strike. Only the portions of the northwest fractures over the arch were utilized by the ore solution which migrated along the crestand then worked its way into the overlying 7-rock along the fractures. Thus there is a dual control. This situation is repeated many times in the Flat River area.

The sedimentary arch type of structure has not been recognized outside the principal mining area.

Fracture zones.—The influence of fractures in conjunction with arch structures in the 7-10 contact has been mentioned above. In certain areas where arches are absent, mapping of ore trends clearly shows a relation to faults or fracture zones, even though the majority of the larger ore trends, guided by depositional features, seem to cross fault structures indifferently. The southwestern margin of the Flat River area is suggestively parallel to the adjacent Simms Mountain fault. Here and elsewhere instances of possible fracture control are common in the 7 zone. The Federal No. 9 Mine, on the eastern extremity of the Flat River area, is a good example (Fig. 11). Here many narrow ore bodies trend northwest in association with an interesting type of structure known as a "roll" (Pl. 4). "Rolls" are elongate, commonly higher than wide, and may extend for several hundred feet. Some terminate against northeast-trending faults. Within a "roll" the normally thin-bedded, gray-spotted 7-zone rocks are intensely fingered, have a thick-bedded structure defined by irregular, heavy shale partings, and show strong apparently upwarped arches and down-bent V's formed by the thickened beds. The sharp V's often show as troughlike crenulations in the back, hence the term "roll". Here mineralization is particularly concentrated in areas up to 10 feet wide and up to 50 feet or even more in height. The intense contortion of the thick layers suggests strong compressional deformation, but the absence of any corresponding effect in beds above or below has led most observers to conclude that this is only apparent.

The interfaces between fingered and non-fingered material at the margins of "rolls" are

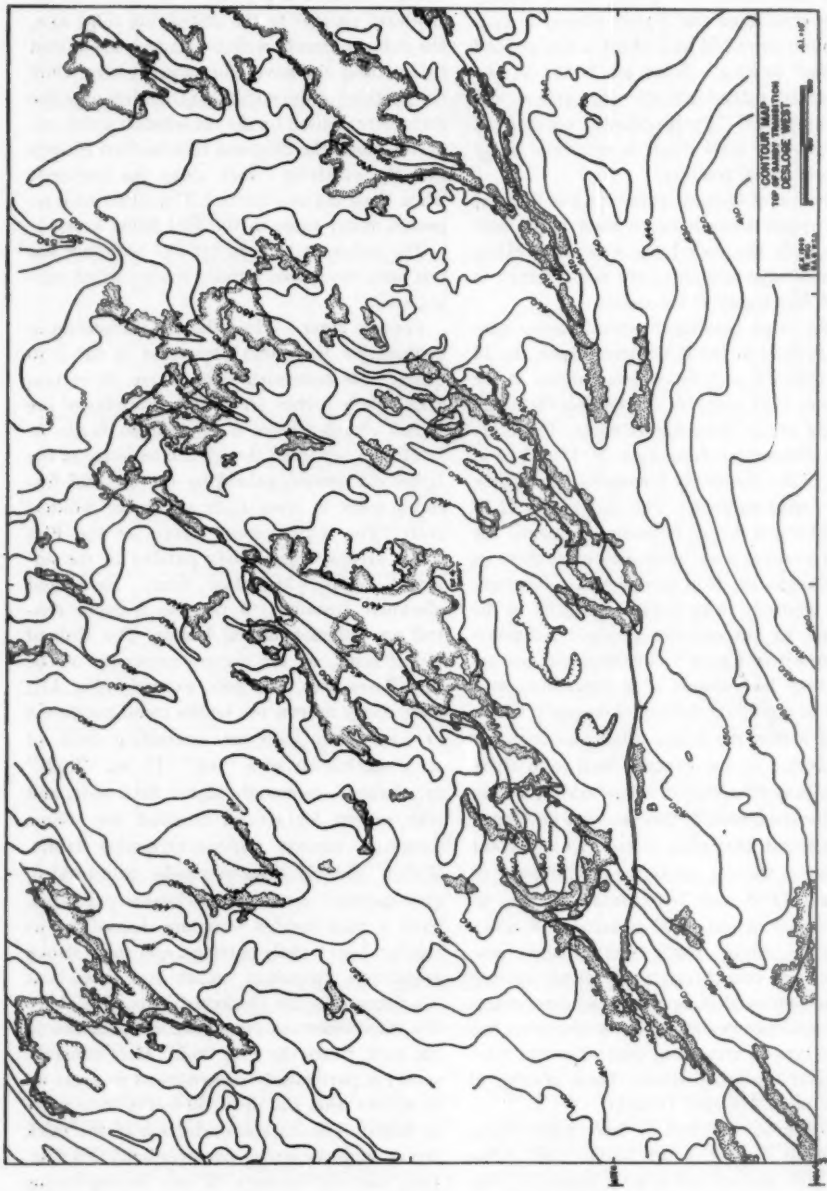

FIGURE 6.—DESLOGE MINE SANDY TRANSITION CONTOUR MAP

Showing the configuration of the top of the 19-zone and the mined ore bodies (stippled) related to "sandridge" structures. Originally the ridge axes sloped northeastward, but the direction was reversed by movement on the Simms Mountain fault.

FIGURE 6.—DESLOGE MINE SANDY TRANSITION CONTOUR MAP

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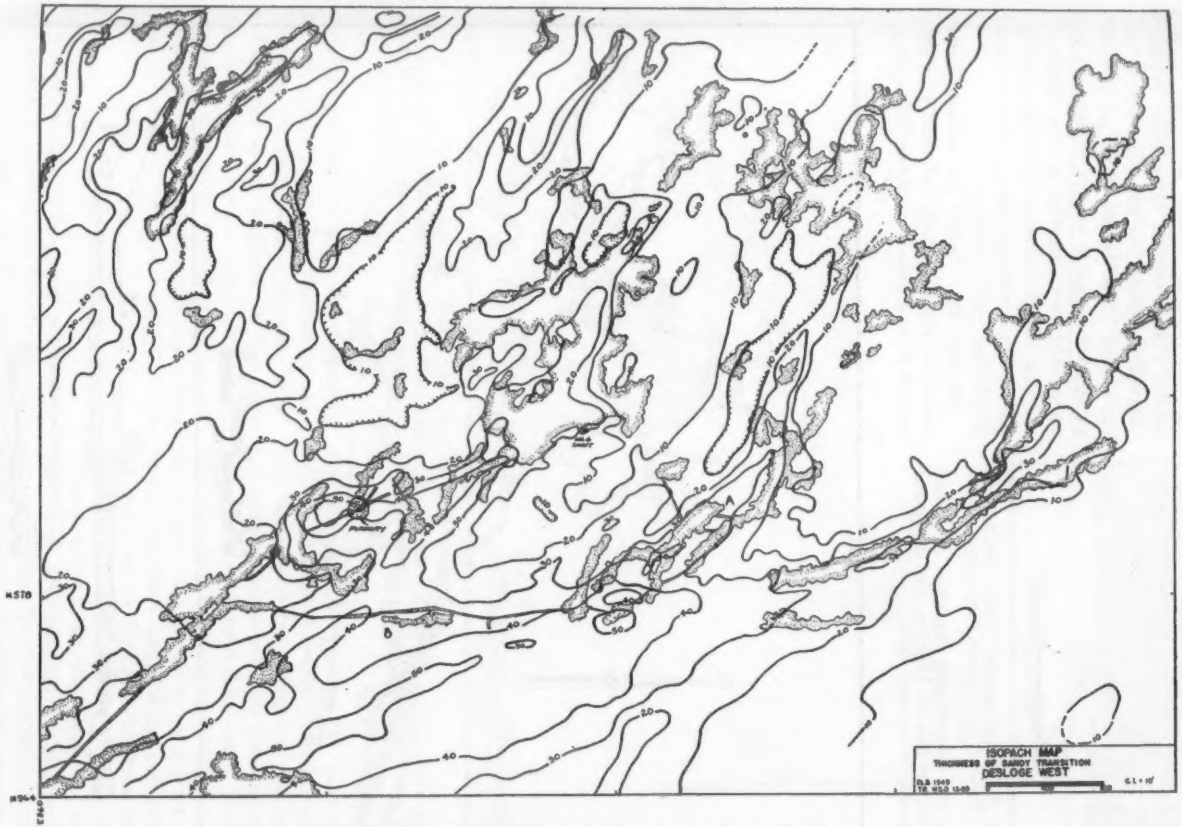

FIGURE 7.—DESLOGE MINE SANDY TRANSITION ISOPACH MAP

Showing by isopachs the thickness of the sandy dolomite in the same area shown in Figure 6. Note the decrease in ridge thickness from southwest to northeast. Mined ore bodies are stippled.

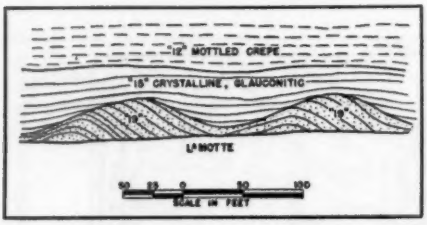

FIGURE 8.—DIAGRAMMATIC CROSS SECTION OF TYPICAL SAND-RIDGE STRUCTURES

Note the compensating deposition of 15-rock which tends to hide the 19 ridges. Also the internal cross-bedding in the sandy rock.

shattered in many places with the closely spaced fractures being individually of limited vertical extent. Galena veinlets filling these fractures contribute a minor but important part of the ore values. These broken zones possibly are explainable as due to volume adjustments accompanying the alteration process. Many of the long, narrow, northwest-trending stopes in the district are mining one or more of these mineralized "roll" interfaces.

The fact that "rolls" are almost always parallel in any given area, and usually are also parallel to the dominant northwest fault system,

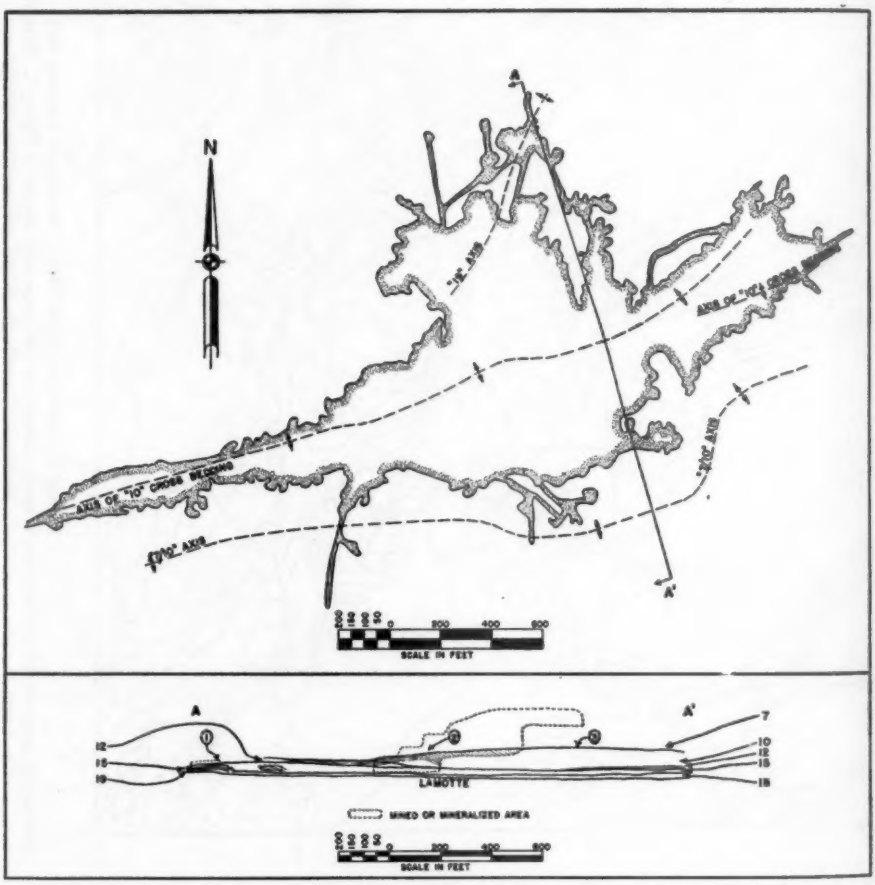

FIGURE 9.—MAP AND SECTION SHOWING PROGRESSIVE SOUTHWARD SHIFT OF RIDGE AXES

No. 4 National Mine at Flat River. Note how the 19 depcsition crests at (1) in the cross section, the 10 cross-bedding at (2), and the 7/10 contact at (3). Mined area is stippled.

strongly suggests some structural relation controlling the alteration. Occasionally in an area of "rolls", fractures with a similar trend do exist and extend upward and downward into the enclosing rock units, but much more commonly no such guiding master fractures can be seen. Therefore, the exact relation between "rolls" and fractures is still unsolved. It does seem clear that "rolls" were channels of intensive circulation of altering solution prior to and possibly in close connection with mineralization.

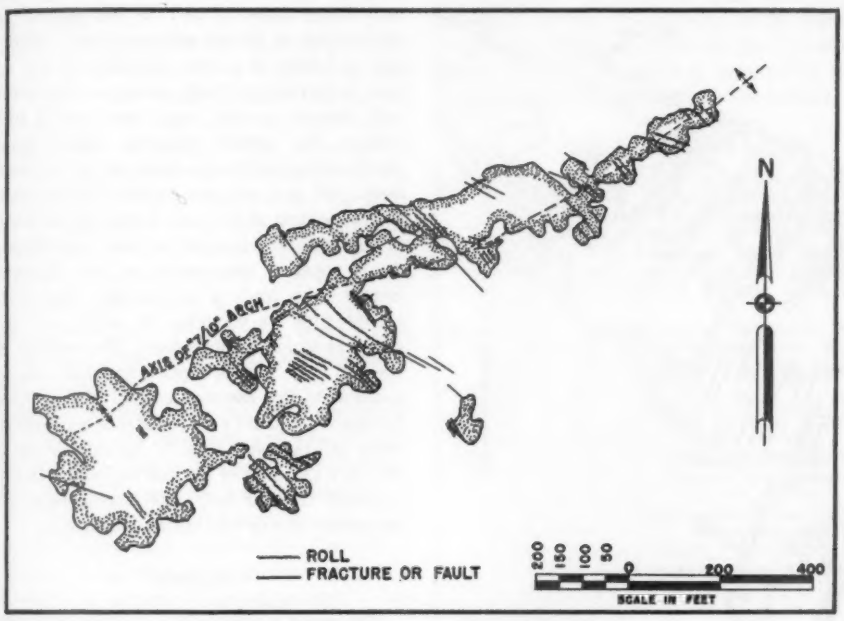

FIGURE 10.—MAP OF 7/10 ARCH

A Portion of No. 5 Federal Mine at Flat River showing the relation of a trend of high mining (stippled) to a 7/10 arch. The richest ore concentrations in the "7-rock" coincided with the northwest fractures and "rolls" indicated on the map.

4. *Ore Genesis*

Problems of the source, method of transport, and manner of deposition of the ore are, as in all other areas, difficult, obscure, and not at present susceptible of definite solution. It is hoped that the complete survey of the area will contribute something to the ultimate understanding of such matters. It is generally believed by most of those working on the program that the ore solutions originated at depth and rose along fractures in the Precambrian basement, though other alternatives are not excluded. The relation of certain ore deposits to the "sand pinchout line" around Precambrian knobs suggests that the Lamotte was an important pathway of solution migration—with the flow leading especially to structurally high areas. In these areas and especially where the sand wedges out, the solution was forced to ascend into the Bonneterre where precipitation occurred. In the main part of the Lead Belt considerable migration through the dolomite itself seems to have occurred with the direction of movement being predominantly northeastward up the regional dip. The flow throughout much of the district was restricted to the lower Bonneterre by an overlying blanket of impervious limestone and in many places was concentrated along the axial lines of arch structures. This preference for domes and arches is the best evi-

dence that the solutions were trying to rise. The analogy to the accumulation of oil on structural highs is rather remarkable.

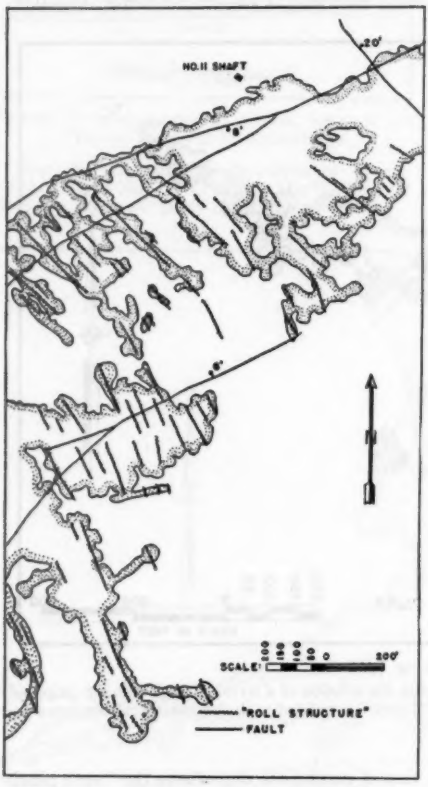

FIGURE 11.—MAP OF A PORTION OF NO. 9 FEDERAL MINE

Showing numerous narrow, northwest-trending stopes (stippled) related to "roll" structures, and the limitation of these "rolls" to the southeast side of the northeast fault passing near No. 11 shaft.

All workers in the program seem agreed that at the time of deposition in the Bonneterre formation the mineral was being carried in an aqueous fluid guided by structural controls and circulating most freely in the more permeable parts of the rock section. It is evident that the amount of lateral movement through the dolomite was many times greater than the vertical component. Actual permeability measurements of the various rock types are under way. There is much evidence in the deposits that bedding planes influenced circulation and ultimate deposition far more than did fractures.

Lead Belt ore is rather unique among deposits of the Mississippi Valley type in its great preponderance of lead over zinc, the ratio being about 50 to 1. Is this due to the composition of the ore solution or is it simply due to failure of a more abundant supply of zinc to precipitate? Such zoning as does occur with respect to lead, zinc, iron, and copper follows this general pattern: copper (plus cobalt and nickel) at the base, lead in the main body, and zinc and iron upward and outward at the margins of the lead. A systematic study of these relations has not yet been undertaken. As it appears, zinc seems to have traveled farther than lead—a relationship that is in accord with its solubility in dilute aqueous solutions at low temperatures. The position of the still more soluble copper, however, fails to conform to this assumed control of deposition by solubility. Until a more detailed paragenetic study can be undertaken, it can only be stated that zinc and most of the iron deposition clearly preceded that of lead, and considerable replacement of zinc by lead has occurred.

SUMMARY

This paper is essentially a progress report on the geological study being made in the Southeast Missouri Lead Belt by the St. Joseph Lead Company. The problems encountered are described together with an appraisal of the progress toward their solution. These problems have consisted of: (1) the subdivision of the Bonneterre formation into units that can be mapped underground and the establishment of a rock-classification system; (2) the recognition and interpretation of rock types resulting from alteration; (3) the recognition and mapping of the structural controls of the ore bodies; (4) the collection and interpretation of data which may indicate the method of ore genesis.

Much of the internal stratigraphy of the Bonneterre was known prior to 1947 as a result of study of thousands of diamond-drill cores. This information has been supplemented by underground observation, and the formation is divided into eight principal zones numbered from top to bottom 1, 3, 5, 7, 10, 12, 15, and

19. Contacts between these units are readily mapped, and structural features are indicated by contouring. Ore in each zone has distinctive characteristics so that pay holes can be evaluated according to the position of the ore in the formation.

The influence of buried Precambrain knobs on some ore bodies in the district has been known for many years. Detailed underground mapping in the main Lead Belt area has revealed that sedimentary arch structures of depositional origin are the outstanding features controlling ore trends. These arches, or ridges as they are called locally, trend northeast for the most part and may be found at several horizons in the lower 200 feet of the formation. Fracture zones exerted a secondary influence where arches were present and, where arches were absent, were the dominant ore-controlling structures.

Rock alteration of several types preceded or accompanied ore deposition and affected rock in zones of varying width around the ore bodies. Major alteration effects are dolomitization of limestone, gray spotting and fingering, recrystallization, and removal by dissolution. Glauconite and adularia are distributed in such a way as to suggest a secondary origin or, at least, secondary redistribution.

The position of the ore with respect to limestone and the tendency of ore to occur associated with arches and domes rather than synclines and basins indicate that lateral migration of the ore solution was important and that the vertical component of motion of the solution almost surely was up rather than down. The marginal position of sphalerite in the galena ore bodies, indicating that the zinc traveled farther from the source, is in accord with the relative water solubilities of the two sulfides.

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CORRELATION OF THE CRETACEOUS FORMATIONS OF GREENLAND AND ALASKA

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INTRODUCTION

This is Number 10d of a series of correlation charts prepared for the Committee on Stratigraphy of the National Research Council.[1] It has been sponsored by the U. S. Geological Survey and has required about 7 months' time of both authors gathering and compiling data and evaluating fossil evidence. As the two regions dealt with are widely separated, the lists of references are also given separately. The annotations dealing with Greenland are based entirely on published information. The annotations dealing with Alaska are based on a re-examination of nearly all the Cretaceous fossils from Alaska in the collections of the Geological Survey. This has resulted in many concepts not hitherto published and in some concepts that are completely at variance with those that have been published. Naturally for large areas undergoing active exploration, such as Alaska, a correlation chart is out of date in many particulars as soon as published. Nevertheless it is valuable to the field man whose activities are confined to small areas but who must interpret many of his data in terms of surrounding areas that he has not seen. It is valuable to the student and to the general geologist because it organizes scattered information in a manner that can be applied in their field problems, makes quite unnecessary the memorization of stratigraphic sections and fossil names, and shows clearly that stratigraphic correlations are based on observation and reasoning and not on a vast memory. It is probably of greatest value to the specialist who makes the chart because he discovers what areas and problems are most in need of research and can thereby direct his efforts and those of his associates in a manner that will yield the greatest results.

[1] Dunbar, C. O., *et al.* (1942) Correlation charts prepared by the Committee on Stratigraphy of the National Research Council, Geol. Soc. Am., Bull., vol. 53, p. 429–434.

ANNOTATIONS

1. In eastern Greenland (Fig. 1) the Aptian and Albian stages of the Lower Cretaceous are represented mostly by black to gray shale containing orange- to red-weathering concretions or thin beds of clay ironstone. Some sections contain intercalations of light-yellow marl and yellow to brown siltstone, sandstone, or conglomerate. Sandstone dominates in the Aptian part of the sequence on Koldewey Island and on the northwestern part of Hold-with-Hope and is locally common in the Albian. In a few places occur enormous angular blocks interpreted as landslide material derived from fault scarps bordering the sea. The base of the sequence rests on an irregular surface composed of basal Cretaceous, Jurassic, Triassic, Permian, or older rocks. Locally in the Falskebugt area of eastern Wollaston Foreland, the

Aptian rests on the Valanginian beds with angular discordance of about 24°. The thickness of the sequence is estimated to be more than 2000 meters (Maync, 1949, p. 195–211).

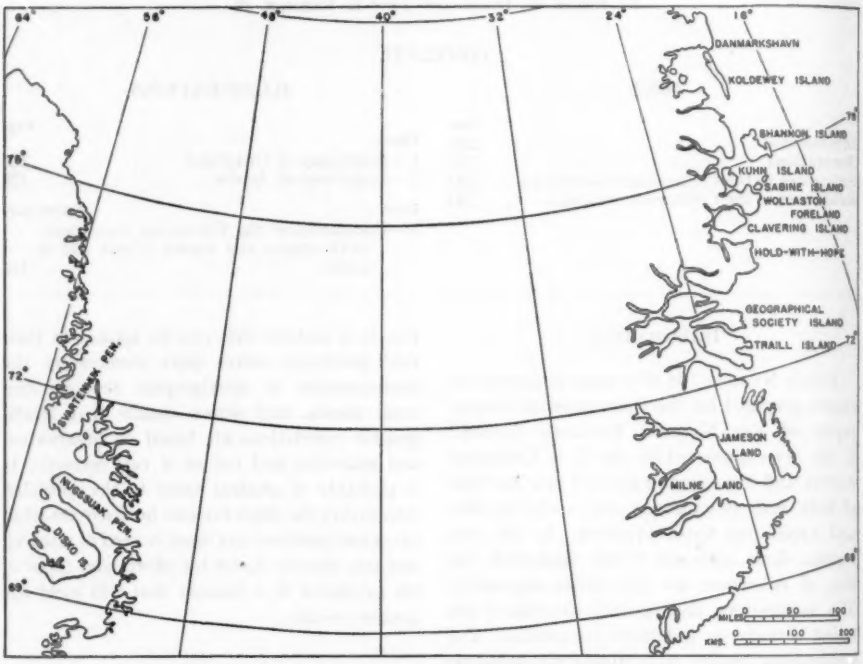

FIGURE 1.—INDEX MAP OF GREENLAND

The record of Aptian in East Greenland is based mainly on the occurrence of the ammonites *Deshayesites*, *Sanmartinoceras*, *Ancyloceras*, and *Tropaeum* (Bogvad and Rosenkrantz, 1934; Frebold, 1935; Spath, 1946; Donovan, 1953, p. 136). On the basis of published studies in England and France (Spath, 1930; Roch, 1927; Kilian and Reboul, 1915), *Ancyloceras* is characteristic of the lower Aptian and is rare in the Barremian, *Deshayesites* is characteristic of the upper part of the lower Aptian but ranges into the lower part of the upper Aptian, and *Tropaeum* ranges from the upper part of the lower Aptian into the lower part of the upper Aptian. The genus *Sanmartinoceras* was considered by Whitehouse (1926, p. 204) to be restricted to the uppermost Aptian on the basis of occurrences in Australia. He considered the records from the lower Aptian of Germany to be in error. However, in the middle of the Cogollo formation in Sierra de Perijá, Venezuela, *Sanmartinoceras* is associated with *Colombiceras*, *Deshayesites*, and *Cheloniceras* aff. *C. cornuelianum* (D'Orbigny). As *Colombiceras* has not been found below the upper Aptian, this association probably represents the base of the upper Aptian rather than any part of the lower Aptian, provided that the ammonites were all obtained from the same bed. It may be significant that *Sanmartinoceras* has not been found in the highest Aptian beds of Mexico (Humphrey, 1949), Colombia (Riedel, 1937), or Venezuela in association with *Dufrenoya justinae* (Hill). On the basis of the ammonites collected in Greenland only part of the lower Aptian has been definitely identified, but part of the upper Aptian may be represented by *Tropaeum* and *Sanmartinoceras*. Neither the very lowest or highest Aptian has been identified faunally in Greenland.

The lower and middle Albian are represented in East Greenland (Spath, 1946, p. 8–10; Donovan, 1953, p. 136, 137) by several ammonite assemblages, whereas there is a lack of any typical upper Albian ammonites. The impressions referred questionably to *Gastroplites* by Spath do not indicate the upper Albian, because the only accurately dated occurrences of the genus are in the middle Albian in England (Spath, 1937, p. 257), and in Alaska. (See Annotations 14, 31, 46) The record of *Gastroplites* in the Mowry shale in the western interior region of the United States is now considered erroneous by Cobban and Reeside contrary to published statements (Cobban and Reeside, 1951, p. 1892, 1893; Cobban, 1951, p. 2179). This record was once considered significant because the Mowry is definitely younger than the middle Albian (Reeside, 1923, p. 200).

The age of the upper part of the Aptian and Albian sequence in East Greenland probably varies from one locality to another owing to erosion before deposition of the capping basalts and sediments of early Tertiary age. However, the amount of erosion has not been ascertained and may not be determinable owing to scarcity of fossils. For the purposes of the chart, it is assumed that the upper part of the sequence in each general area corresponds to the boundary between the middle and upper Albian.

2. The Berriasian (used in same sense as Infravalanginian) has been found in East Greenland in only two areas: (1) the Scoresby Sound district and (2) southwestern Kuhn Island and the near-by northwestern part of Wollaston Foreland. Its absence elsewhere in East Greenland is explained partly by pre-Aptian erosion and partly by nondeposition.

In the Scoresby Sound district the main occurrence is in southern Jameson Land (Aldinger, 1935, p. 38; Spath, 1947, p. 49), where ammonites were obtained in the upper part of about 500 feet of dark sandy shale and soft, thin sandstone and in a shelly bed at the base of the overlying 330 feet of cross-bedded sandstone. These ammonites were placed by Spath (1947, p. 53–57) in *Subcraspedites* and a new genus *Hectoroceras*, which he considered as probably earliest Cretaceous rather than latest Jurassic.

In the area comprising southwestern Kuhn Island and adjoining parts of Wollaston Foreland, the Cretaceous section (Maync, 1949, p. 27–32, 96–100, 183) begins with 100 meters of banded sandstone and shale containing large boulders. The highest boulder bed, about 30 feet below the top, contains two *Subcraspedites* that Spath (1946, p. 4; 1947, p. 58) considers Cretaceous. These are associated with ammonites that are reported to be reworked from Jurassic strata. Next above follows 40 meters of gray to reddish sandstone and sandy limestone that contain craspeditid ammonites, including one specimen that Spath (1947, p. 58, Pl. 3, fig. 2) refers questionably to *Hectoroceras*. Above this follows beds 55 meters thick that include gray sandy shale interbedded with hard limestone, a covered interval, and then some sandy limestone. This is succeeded by 75 meters of red to brown sandy shale and interbedded sandy limestone. Ten meters below the top of this unit was obtained one specimen of the ammonite *Tollia* which is characteristic of the Berriassian (Infra-Valanginian) in northern Siberia and Novaya Zemlya.

3. The middle Valanginian exists in two contrasting facies that grade into each other laterally and at places vertically (Maync, 1949, p. 185–192). The Albrechts Bay facies, named from north-central Wollaston Foreland, consists of gray, yellow, or pink marl and marly shale containing limestone beds and nodules. The Young Sound facies consists of coarse breccias and conglomerates, locally unstratified and unsorted, embedded in a matrix of sandstone and including lumps and lenses of gray or yellow limestone that bear numerous aucellas. This facies, which Maync interprets as forming at the base of fault scarps, passes upward in some sections in central Wollaston Foreland into gray to yellow, partly sandy limestone. The Falskebugt beds in eastern Wollaston Foreland display a similar mixed facies. The assignment of a middle Valanginian age to these beds is based on such ammonites as *Polyptychites*, *Euryptychites*, *Dichotomites*, and *Neocraspedites* (Spath, 1946, p. 6; Donovan, 1953, p. 102–115). There is no faunal evidence for the presence of lower Valanginian, and, judging by the sections in northern Wollaston Foreland, there are only a few meters of red-

brown sandstone that might represent the lower Valanginian.

4. The upper Valanginian in eastern Kuhn Island and in most of Wollaston Foreland is represented by 15 meters or less of red sandstone, breccias, and locally marl and coquinoid limestone which Maync (1949, p. 70–72, 192) has named the Rødryggen beds. Somewhat similar red beds in northwestern Wollaston Foreland have furnished a single specimen of *Lyticoceras* (Maync, 1949, p. 98), which Spath (1946, p. 6) considers is probably upper Valanginian rather than lower Hauterivian.

5. From 90 to 450 feet of light-gray, micaceous sandstone and dark-gray, brittle sandy shale exposed near Knudshoved on the eastern coast of Hold-with-Hope furnished pelecypods that Frebold (1934, p. 9–27) identifies with *Pteria tenuicostata* Roemer and *Inoceramus* similar to *I. cardissoides* Goldfuss and considers to be of late Emscherian age, which is early Santonian as used herein. Frebold (1934, p. 21) also made the same age assignment for a specimen of *Pteria tenuicostata* Roemer from Home Foreland at the northeast end of Hold-with-Hope. However, Maync (1949, p. 136, 137, 212–214) examined the sequence at Home Foreland and concluded that it belonged lithologically and faunally with the Aptian and Albian sequence. He did not find a single specimen of *Pteria* at Home Foreland and suggests the possibility of mislabeling of the specimen reported from there. He notes that Andreas Vischer (Maync, 1949, p. 144) at a locality 2 km south of Knudshoved found the light-colored sandy Knudshoved beds marked basally by a thin conglomerate that rests on dark marly beds such as are exposed widely at Home Foreland. Maync (1949, p. 215, 217) concludes that exposures of the Upper Cretaceous strata of Santonian age are confined to the vicinity of Knudshoved. Donovan (1953, p. 53) considers that determination of the age of the beds at Home Foreland must await the discovery of better fossil evidence.

Some shaly rocks on Traill Island have furnished pelecypods of about the same age as those in the Knudshoved beds (Donovan, 1953-p. 43, 88, 93–95, 138). The presence of *Inoceramus steenstrupi* de Loriol and *I. patootensis* de Loriol indicates a correlation with at least part of the Patoot beds in West Greenland (*See* Annotation 8) and with the upper Santonian to lower Campanian of Europe (Donovan, 1953, p. 95).

At one locality on Traill Island Donovan (1953, p. 44, 121–125, 138) found several fragments of *Scaphites*, of which he identified one with *Acanthoscaphites quadrangularis* (Meek and Hayden). If correctly identified this species indicates an upper Campanian age.

6. Spath (1946, p. 10) has identified the lower Cenomanian ammonite *Schloenbachia* in collections from Traill Island and the southern part of Geographical Society Island (Stauber, 1938; Donovan, 1949, p. 8; Donovan, 1953, p. 119). He also identified the Turonian ammonites *Scaphites* aff. *S. lamberti* (de Grossouvre) and *Prionotropis* cf. *P. woolgari* (Mantell) (equals *Collignoniceras woollgari*) from Geographical Society Island. These indicate the lower part of the upper Turonian. Donovan (1953, p. 120–124, 137) has described two species of Turonian *Scaphites* from Traill Island.

7. Marine shale cropping out on the north shore of the Nugssuak Peninsula in West Greenland have furnished ammonites and pelecypods representing the Coniacian to Maestrichtian stages of the Upper Cretaceous (Loriol, 1893; Madsen, 1897; Ravn, 1918, p. 309; Frebold, 1934, p. 25–27). The presence of the Turonian stage has not been proven. The Coniacian is represented by *Scaphites* similar to *S. ventricosus* Meek and Hayden (Rosenkrantz, 1942, p. 39, Pl. 1). The Maestrichtian is represented by ammonites referred variously to *Acanthoscaphites roemeri* (d'Orbigny) and *Discoscaphites nicolleti* (Morton). A number of pelecypods listed by Ravn (1918) from West Greenland occur in the western interior of the United States in beds of Campanian to Maestrichtian age (White and Schuchert, 1898, p. 356, 357).

8. The Patoot beds in the southern part of the Nugssuak Penninsula have furnished a flora regarded as of latest Cretaceous age (Heer, 1883; Ravn, 1918) and at Patoot have furnished species of *Inoceramus* that in Europe are reported to be restricted to the upper Santonian (Heinz, 1928; Maync, 1949, p. 279). The age limits of the Patoot beds are not known. Possible they are entirely of Santonian age.

9. The Atane beds carry a dicotyledonous flora that was once considered to be of Senonian

age (Heer, 1883; Ravn, 1918). However, they are overlain by marine shales carrying *Scaphites* similar to *Scaphites ventricosus* Meek and Hayden and, therefore, cannot be younger than the Turonian. The Atane beds are reported to be separated from adjoining formations by unconformities.

10. The Kome beds contain a flora that was at first referred to the Barremian and Aptian stages (Heer, 1883) but later because of the presence of a dicotyledon was referred to the Albian (Berry, 1911; Ravn, 1918). Brown (1946, p. 246, 247) notes that the Kome beds contain many species in common with the Kootenai formation of Montana and with the Lower Blairmore formation of Canada and that the Lower Blairmore has furnished a single dicotyledon. The Lower Blairmore formation is correlated with the Aptian stage on the basis of its flora (Berry, 1929; Bell, 1944). This correlation seems reasonable, because the Lower Blairmore passes northward in Alberta and British Columbia into interbedded nonmarine and marine beds that underlie marine beds containing *Lemuroceras* and *Beudanticeras* (McLearn, 1945), both definite Albian genera. The range of *Lemuroceras* is not known, but in Madagascar it occurs with many other ammonites that mark the basal middle Albian zone of *Douvilleiceras mammillatum* (Collignon, 1949, p. 103–110). This dating of *Lemuroceras* shows that the Lower Blairmore might include beds of early Albian age but certainly nothing younger. By comparison the Kome beds of West Greenland probably represent the Aptian and part of the Albian.

11. Some shales exposed on the coast of the southern part of the Svartenhuk Peninsula have furnished ammonites related to *Scaphites ventricosus* Meek and Hayden (Rosenkrantz, 1942, p. 38). Such *Scaphites* in the western interior of the United States are not known in beds older than the Coniacian. Associated with them in West Greenland are specimens that "seem to belong to the genus *Borissjakoceras*" (Rosenkrantz, 1942, p. 39). This genus in the western interior is known only in beds of Cenomanian and Turonian age not younger than the lower part of the Carlile shale. Possibly the ammonite from West Greenland really belongs to the genus *Binneyites*, which is similar to *Borissjakoceras*.

12. In southeastern Alaska (Fig. 2) the presence of beds of Berriasian age is indicated by one large collection of *Aucella subokensis* Pavlow (Mes. loc. 10147) from Slocum Arm on the west side of Chichagof Island. The presence of beds of Valanginian age is indicated by typical specimens of *Aucella crassicollis* Keyserling from Kruzof Island (Mes. loc. 17845), Admiralty Island (Mes. locs. 8850, 8855), and Etolin Island (Mes. locs. 8840, 11077). On Admiralty Island at Pybus Bay this species occurs in 300 to 400 feet of dark-gray shale which is underlain by conglomerate and pebbly shale at a point between two arms of the bay (Martin, 1926, p. 377–378). This pebbly shale has furnished many specimens of *Aucella* (Mes. locs. 3309, 8851, 10095, 10169) that belong to *A. piochii* Gabb or to similar species characterized by an elongate form and narrow umbo. Such aucellas in California are common in the latest Jurassic Knoxville formation and rare in the overlying Early Cretaceous Paskenta group (Anderson, 1945, p. 964, 965). In Europe and Asia they characterize beds of Portlandian age. The aucellas that have been obtained from Kupreanof Island and Gravina Island (Martin, 1926, p. 253, 379–382) are not of Early Cretaceous age, as they belong to *Aucella rugosa* (Fischer) and *Aucella* cf. *A. mosquensis* (von Buch), which in Russia range through the upper Kimmeridgian into the basal Portlandian not higher than the zone of *Zaraiskites albani* (Arkell, 1946, p. 24–26; Spath, 1936, p. 167; Pavlow, 1907, table opposite p. 84).

13. The Mesozoic is represented along the mountainous Pacific Coast of Alaska from Yakutat to Kodiak Island by a thick sequence of slate, graywacke, arkosic sandstone, minor amounts of conglomerate and grit, and large masses of dark extrusive and intrusive rock. These rocks have been included in the Yakutat group in the Yakutat Bay area, in the Valdez and Orca groups in the Chugach Mountains north of Prince William Sound, and in the Sunrise group on the Kenai Peninsula (Martin, 1926, p. 480–487; Moffit, 1938, p. 89–92). Throughout this distance of nearly 700 miles reliable fossil evidence concerning the age of these Mesozoic beds has been found in only three small areas—one on Barry Arm in the Port Wells district north of Prince William

Sound, one near Girdwood on the north side of Turnagain Arm southeast of Anchorage, and one on a small island near Kodiak. Curiously, these three areas contain identical species from Turnagain Arm. Both of these species are associated in the western interior in the *Scaphites binneyi* zone at Mes. loc. 21097 in the lower part of the Cody shale, Wyoming, and

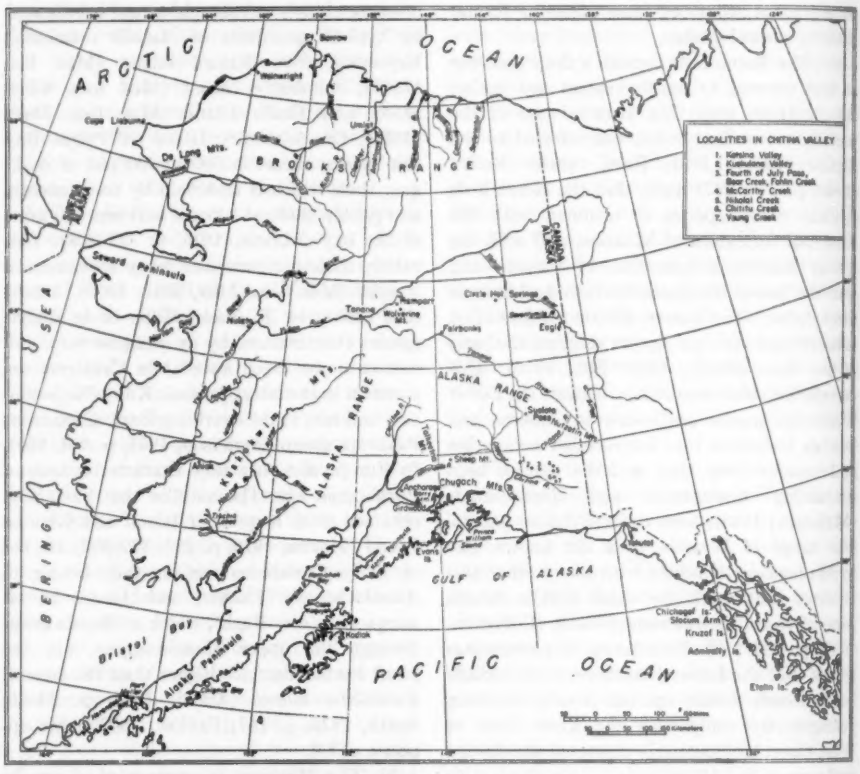

FIGURE 2.—INDEX MAP OF ALASKA

of *Inoceramus* characterized by bearing radial marking. The collections from Girdwood (Mes. locs. 7238, 7378, 15965–15968) and Barry Arm (Mes. loc. 8601) contain species of *Inoceramus* that can be matched with western interior species that occur in the zone of *Scaphites binneyi* Reeside (Cobban, 1951a, p. 2197). One of these species obtained near Kodiak was described by Ulrich (1904, p. 134–136, Pl. 12, figs. 1, 2; Pl. 13, fig. 1) as *Inoceramya concentrica* Ulrich. On the same slab as the type of "*Inoceramya*" *concentrica* Ulrich is a fragment of another *Inoceramus* with strong radial ribbing identical with one of the species at Mesozoic locality 11951 in the Mancos shale near Price, Utah. The corresponding position in Europe would be either upper Coniacian or lower Santonian.

The Late Cretaceous age shown by these species of *Inoceramus* at the three localities is supported by the occurrence of a comatulid crinoid on the west side of Evans Island in the western part of Prince William Sound near the Kenai Peninsula (Johnson, 1916, p. 198). A. H. Clark reported that this crinoid belongs to a group not known before the Jurassic and is closely related to a crinoid now living in Alaskan waters.

The close dating of the thick sequence of slate and graywacke at only three places is not evidence that the entire sequence is so narrowly dated throughout its area of distribution. It probably represents much more than the small interval of time indicated by the *Inoceramus*. For example, R. P. Sharp collected earliest Cretaceous aucellas in graywacke in the St. Elias Mountains, Canada, on a ridge about 10 miles due east of the summit of Mt. Logan and 4 miles southeast of McArthur Peak. According to Don J. Miller (Personal communication, January 9, 1951), "These fossils apparently are from a graywacke sequence which is widespread in the Alaskan part of the St. Elias Mountains and which forms a considerable part of the Chugach Mountains farther west."

The aucellas in question are poorly preserved, but comparisons may be made with *Aucella okensis* Pavlow, *A. subokensis* Pavlow, and *A. volgensis* Lahusen. If correctly identified, these would represent the Berriasian stage of the very base of the Lower Cretaceous. Regardless of specific identity, they are large, stout aucellas such as characterize the earliest Cretaceous of the Boreal region and the Pacific Coast of North America from California northward.

Considering these age determinations and the age distribution of Cretaceous deposits in other parts of Alaska, it seems probable that the slate and graywacke sequence includes equivalents of all the Cretaceous to the north in the Copper River region, in the Cook Inlet region, and in southwestern Alaska, and was originally deposited as sediments in the same seas that covered those regions. This statement does not preclude the possibility that Jurassic or older rocks may somewhere be represented in the slate and graywacke sequence.

14. The Kennicott formation of the Chitina Valley, as defined by Martin (1926, p. 349), includes Lower Cretaceous strata at Fourth of July Pass, Kuskulana Pass, Bear Creek and Fohlin Creek east of Kuskulana Pass, and the headwaters of McCarthy Creek. Generalized sections of the Lower Cretaceous deposits have been published by Moffit (1938, p. 71–78), who notes that the basal beds are generally conglomerate or grit of irregular thickness. These are overlain by 300 to 500 feet or more of sandstone and sandy shale that contain calcareous concretions. Above follows black shale that locally is at least 3000 feet thick and includes some sandstone and conglomerate. At the top is 2500 feet or more of conglomerate, sandstone, and sandy shale that have not furnished fossils and may be younger than the early Cretaceous. Studies of the mollusks of the Kennicott formation show that at least three assemblages are present. Two of these assemblages include species identical with species in the upper part of the Horsetown formation of California (Anderson, 1938). The other assemblage is possibly present in California but is certainly present on the Queen Charlotte Islands and has been described by Whiteaves (1876; 1879; 1884; 1893; 1900; 1903).

The molluscan assemblage best represented in the Geological Survey collections from the Kennicott formation is probably the oldest. It is characterized by an abundance of the pelecypod *Aucellina* and is the only assemblage that contains this genus. It includes such ammonites as *Lemuroceras deansii* (Whiteaves), *L.* cf. *L. besairiei* (Collignon), *L.* cf. *L. indicum* (Spath), *L. lecontei* (Anderson), *L.* cf. *L. taffi* (Anderson), *Pseudosonneratia* sp., *Sonneratia? rogersi* Hall and Ambrose, *Puzosia subquadrata* Anderson, and *Lytoceras* (*Kossmatella*) *aurarium* Anderson. Identical or similar species are present in the upper part of the Horsetown formation in beds that Anderson (1938, Table 2, p. 68) refers to his LeConte and Perrin zones. This assemblage is well represented in collections from U.S.G.S. Mes. locs. 2147, 2191, 2201, 8872, 8873, 8876, 8877, 8878, 9478, 9489, 9971, 9972, 9978, 14485, 14487, and 14848 in the Kennicott formation.

A second assemblage considered slightly younger than the preceding is represented by a large collection from U.S.G.S. Mes. loc. 9492. It contains such ammonites as *Arthoplites* cf. *A. jachromensis* (Nikitin), *Cleoniceras*, *Beudanticeras haydeni* (Gabb), *B. breweri* (Gabb), *Lytoceras* (*Tetragonites*) *timotheanum* (Mayor), and *L.* (*Gaudryceras*) *sacya* Forbes and the pelecypods *Inoceramus concentricus* Parkinson and *I.* cf. *I. anglicus* Woods. Many of these species are identical with species occurring near the top of the Horsetown formation in beds that Anderson (1938, Table 2, p. 68) refers to his Neptune zone.

A third assemblage, represented at Mes. locs.

9481, 9485–9487, 14511, and 14514, contains the same species of *Beudanticeras* and *Lytoceras* as the second assemblage, but in addition contains the ammonites *Holcodiscoides cumshewaensis* (Whiteaves) (1884, p. 208, Pl. 24, fig. 1; 1900, p. 278) and *H.* aff. *H. papillatus* (Stoliczka) (1865, p. 159, Pl. 77, figs. 7, 8). The common *Inoceramus* is a coarsely plicate form identical with *I. concentricus* var. *subsulcatus* Wiltshire. This assemblage is characterized by the presence of *Holcodiscoides*, which genus was based on a species from the Cenomanian of India (Spath, 1922, p. 124; Stoliczka 1865, p. 157, Pl. 77, figs. 3, 3a). The genus is represented in the Cretaceous of California by a species described by Anderson (1902, p. 101, Pl. 5, figs. 126, 127; Pl. 10, fig. 197).

An Albian age for all three of these assemblages is proven by the occurrence of *Pseudosonneratia*, *Sonneratia?*, *Lemuroceras*, *Cleoniceras*, *Arcthoplites*, *Beudanticeras*, and the species of *Inoceramus* listed.

On the basis of the known ranges of these genera, the assemblage containing *Pseudosonneratia*, *Sonneratia? rogersi* Hall and Ambrose, and abundant *Lemuroceras* represents either the upper part of the lower Albian or the lower part of the middle Albian. This age is confirmed by the identity of some species with species in the LeConte and Perrin zones of Anderson in the upper part of the Horsetown formation in California. This part can be dated approximately by the presence of *Douvilleiceras*, which in Europe ranges through the zones of *Leymeriella tardefurcata* and *Douvilleiceras mammillatum*. A suggestion that the assemblage in question represents the lower rather than the middle Albian is furnished by *Sonneratia? rogersi*, which is similar to the early Albian *Uhligella balmensis* Jacob (1907, p. 33, Pl. 4, figs. 6–9). Also, the identity of the common species in the Kennicott formation with those in the Haida formation on the Queen Charlotte Islands and the presence of *Leymeriella haidaquensis* (Whiteaves) (1893, p. 444, Pl. 7, figs. 2a, b) in those islands suggest that the *Leymeriella tardefurcata* zone is represented in both areas.

The assemblage in the Kennicott formation that contains *Arcthoplites*, *Cleoniceras*, abundant *Beudanticeras* and *Lytoceras*, and the pelecypod *Inoceramus concentricus* Parkinson is probably not older than the *Douvilleiceras mammillatum* zone, because *Beudanticeras* is uncommon and *I. concentricus* is unknown below that zone. *Arcthoplites* in Greenland ranges from the upper part of the lower Albian into the middle Albian (Spath, 1946, p. 9). In Russia it is recorded with *Hoplites dentatus* Sowerby of the middle Albian (Bogoslowky, 1902, p. 128, 153, Pl. 7, figs. 3a–c; Pl. 8, figs. 1a, b; Pl. 6, fig. 4). *Cleoniceras* is not known above the zone of *Douvilleiceras mammillatum*. The identity of some of the species of *Beudanticeras* and *Lytoceras* with species from the highest part of the Horsetown formation in Anderson's Neptune and Packard zones (1938, Table 2, p. 68, 69) suggests a middle Albian age assignment because that part of the Horsetown has furnished the ammonite *Oxytropidoceras* (Anderson, 1938, p. 198, Pl. 50, fig. 1). This genus is typical of the middle Albian, although it has been recorded from the upper part of the lower Albian (Spath, 1942 Pal. Soc. Mon., p. 707). It is interesting that the highest part of the Horsetown formation also, has furnished two species probably belonging to *Gastroplites* (Anderson, 1938, p. 196), which genus is known elsewhere in Alaska, the western interior of Canada, Greenland, and England. It has been precisely dated only in England, where it occurs at the top of the middle Albian (Spath, 1937, p. 257–260).

The third assemblage in the Kennicott formation is undoubtedly only slightly younger than the assemblage with *Arcthoplites* as it contains species of *Beudanticeras* and *Lytoceras* in common, although the presence of *Holcodiscoides* might indicate an age as late as Cenomanian, and the coarsely plicate *Inoceramus concentricus* var. *subsulcatus* Wiltshire might be taken as evidence of late Albian age. However, *Beudanticeras* is not known to range above the basal part of the *Pervinquieria inflata* zone of the late Albian in Europe (Spath, 1942, p. 691), and this well-known genus affords much more positive evidence of age than the poorly known genus *Holcodiscoides*. Also, the coarsely plicate variety of *Inoceramus concentricus* is reported to be characteristic of the zone of *Pervinquieria inflata*.

In summation, the Kennicott formation contains three molluscan assemblages that

can be correlated with certainty with beds of the Albian stage of the latest early Cretaceous in California, in the Queen Charlotte Islands, and in Europe. The evidence is so overwhelmingly in favor of such a correlation that students of mollusks would accept the age determination without qualifications.

In contrast, the students of plant fossils have maintained that the age of the Kennicott formation is either late Jurassic or earliest Cretaceous. Knowlton (Moffit, 1918, p. 42–44; Martin, 1926, p. 344–346) was very positive about this determination, and his conclusions have been confirmed recently by Roland W. Brown (Personal communication) who notes the similarities of the plants with those in the Knoxville formation and Paskenta formation in California. However, the plants in the Kennicott formation are associated with lower and middle Albian ammonites of which many species are identical with species in the upper part of the Horsetown formation of California. Unfortunately the flora in the Horsetown formation has not been described. Bearing on this problem is the identity of some of the plant species in the Kennicott formation with species in the Corwin formation in the Cape Lisburne area of northwestern Alaska (Martin, 1926, p. 456–466), which Knowlton (1914, p. 43) likewise maintained to be of Jurassic age, but which has been traced northeastward into the upper part of the Torok formation of Albian age and into the Nanushuk group which is partly of Albian age.

15. The Matanuska formation has been traced from the head of the Matanuska Valley eastward nearly 40 miles to near Tazlina Lake and probably extends much farther eastward. It has been identified faunally on the north side of the Chitina Valley along Chititu and Young creeks where it is about 8000 feet thick and consists of three members similar to those in the Matanuska Valley area (Moffit and Capps, 1911, p. 31–38; Martin, 1926, p. 360–369). The exposures along these creeks have not been collected stratigraphically, but some fossils obtained from the lower 4500 to 5000 feet of the formation have been identified by Stanton (Martin, 1926, p. 365) as definitely Late Cretaceous. This age determination is now confirmed by the presence of the ammonites *Parapuzosia* (Mes. locs. 4811, 8858, 8862, 8866, 8869) and *Pachydiscus*? (Mes. loc. 8858), and by a fragment of a large *Inoceramus* (Mes. loc. 8860) showing the peculiar digitate ribbing of *I. undulatoplicatus* Roemer. These fossils indicate a Coniacian to Santonian age. The reported occurrence of ammonite shells as much as 18 inches in diameter on the upper slopes of the mountains bordering Chititu and Young creeks (Moffit and Capps, 1911, p. 34) suggests the presence of large pachydiscid ammonites similar to those in the upper part of the Matanuska formation in the eastern part of the Talkeetna Mountains.

Elsewhere in the Chitina Valley the Matanuska formation is probably represented by sandstone and conglomerate that rest unconformably on Triassic rocks at the head of Nikolai Creek (Moffit and Capps, 1911, p. 31–40), at Dan Creek (Martin, 1926, p. 358), and in the Kotsina and Kuskulana valleys (Moffit and Mertie, 1923, p. 20, 44–51). The rather meager fossil evidence consists of an *Inoceramus* comparable to *I. uwajimensis* Yehara at Mes. locs. 2198, 6302, 6309, 8924, and 8936. The occurrence of such an *Inoceramus* indicates that the sandstone and conglomerate in question are probably equivalent to the basal few hundred feet of the Matanuska formation at the head of the Matanuska Valley and in the southeastern part of the Copper River Basin. If these correlations are correct the massive 1000 to 2500 feet of the Kotsina conglomerate in the area of Kotsina River and Strelna Creek (Moffit, 1938, p. 67) is equivalent to the basal part of the Matanuska formation rather than to the lower part of the Kennicott formation.

16. The Matanuska formation in the Matanuska Valley and the eastern Talkeetna Mountains consists of a basal sandstone member as much as several hundred feet thick, an overlying shale member several thousand feet thick, and an upper member of sandstone, siltstone, and shale about 1000 feet thick. Both the basal sandstone and the sandstones near the top of the formation are conglomeratic locally and vary somewhat laterally in thickness and lithologic characteristics. The formation rests unconformably on rocks ranging in age from Early Jurassic to Early Cretaceous. In most places it is overlain concordantly by early Tertiary rocks which sug-

gests that the contact does not represent more than a disconformity. In the mountains west of Kings River, however, the Matanuska formation is reported to be overlain with angular unconformity by early Tertiary rocks (Martin and Katz, 1912, p. 15, 23, 34–39; Martin, 1926, p. 317–321; Capps, 1927, p. 35–40; Personal communication from Arthur Grantz).

The fossils obtained from the Matanuska formation indicate that the formation represents only the upper part of the Upper Cretaceous. The basal sandstone and the immediately overlying several hundred feet of shale are probably of Coniacian age as indicated by their stratigraphic position below shales containing *Inoceramus undulatoplicatus* Roemer, by the presence of *Parapuzosia* and *Prohauericeras*, and by species of *Inoceramus* that are probably identical with *I. uwajimensis* Yehara and *I. naumanni* Yokoyama from the Paleourakawan stage of Japan (Nagao and Matumoto, 1939, p. 286–291, Pl. 34, figs. 1, 3, 4, 6; Pl. 35, figs. 1–3; 1940, p. 31–36, Pl. 14, figs. 1–10; Pl. 15, figs. 1–2). The ammonite *Prohauericeras* occurs in both the Turonian and Coniacian of Europe but is more common in the Coniacian. The species of *Inoceramus* in Japan are associated with some ammonites that are not known above the Coniacian, or are restricted to it, and they overlie beds (Neogyliakian) that contain Turonian ammonites (Matumoto, 1942, p. 147–149). An age younger than Turonian for the basal beds of the Matanuska formation is indicated also by the absence of certain species of *Inoceramus* that characterize beds of Cenomanian to Turonian age in the western interior of Canada, in the Kuskokwim region of western Alaska, and in northern Alaska north of the Brooks Range.

Overlying the lowermost several hundred feet of shale is a somewhat greater thickness of shale containing calcareous concretions and lenses and characterized by many specimens of *Inoceramus undulatoplicatus* Roemer. Fragmentary pachydiscid ammonites were found at two localities. The age of the shale containing *I. undulatoplicatus* Roemer, judging by occurrences of this species in Europe (Woods, 1911, p. 6; Heintz, 1928, p. 76, Pl. 3), Texas (Adkins, 1933, p. 452, 453), and the western interior of the United States (Cobban and Reeside, 1952, p. 1019), is either Coniacian or Santonian and probably mostly early Santonian.

In Japan *I. undulatoplicatus* and its varieties are apparently included under *I. japonicus* Nagao and Matumoto and perhaps also under *I. schmidti* Michael (Nagao and Matumoto, 1940, p. 24–28, 41–44) which occur in the Japanese Neourakawan, Infra-hetonian, and Paleohetonian stages. These have been correlated with the European Santonian, Campanian, and Maestrichtian stages respectively (Matumoto, 1943, p. 229). Judging from the lists of fossils reported from the Japanese stages just mentioned (Matumoto, 1943, p. 127–134, 149–151), there is no positive evidence for placing these stages higher than the Santonian. In regard to correlation Matumoto (1943, p. 229, 230) notes that "We likewise meet with difficulties when we attempt to correlate in detail the finer divisions of the Urakawan + Hetonian with those of the Senonian (*s.l.*), except, however, the Paleourakawan and Coniacian which, in turn, approximately correspond with each other."

Correlation of the Paleourakawan with the Coniacian is based on such ammonites as *Nowakites*, "*Barroisiceras*," and perhaps *Parapuzosia indopacifica* Kossmat. It is evident, however, that the Japanese paleontologists are rather uncertain about correlations of the higher Cretaceous strata. One fact suggesting that some of the Japanese stages for the late Cretaceous may not represent as much time as European stages is the distribution of many of their ammonite species through two or three Japanese stages (Matumoto, 1943, p. 110–134). Such long durations for ammonite species do not agree with the known ranges of most ammonite species in Europe and North America.

Bearing on the age of the beds in the Matanuska formation that contain *Inoceramus undulatoplicatus* Roemer is the occurrence of this species on Vancouver Island (Whiteaves, 1879, p. 168, Pl. 20, figs. 2, 2a). It is presumably the same species referred to as *I.* cf. *I. schmidti* Michael by Ushur (1952, p. 10, 11, 22, 25, 37, 38, 41) in his studies of the ammonite faunas of the Upper Cretaceous of Vancouver Island. He reports this *Inoceramus*

from the Haslam, Qualicum, and Trent River formations which he refers to the Campanian stage, although admitting that the ammonite evidence is not conclusive. His age determination was probably influenced partly by various Japanese publications dealing with Upper Cretaceous ammonites and partly by the fact that the Lambert formation, which occurs only about 1000 feet above the Trent formation, contains an ammonite assemblage that he regards confidently as of Maestrichtian age.

In the Matanuska formation some hundreds of feet of shale lying above beds containing *I. undulatoplicatus* Roemer are poorly exposed and have not furnished fossil material of known age significance. The next higher faunal assemblage was obtained from the lower part of the upper third of the shale member. It is characterized by *Pachydiscus suciaensis* (Meek), *Nostoceras hornbyense* (Whiteaves), *Desmophyllites* ("*Schlüteria*") *selwyniana* Whiteaves), *Neophylloceras ramosum* (Meek), *Gaudryceras denmanense* (Whiteaves), *Diplomoceras notabile* Whiteaves, *Anisoceras cooperi* Gabb, *Polyptychoceras? obstrictum* (Jimbo), and *Inoceramus subundatus* Meek. These species are found elsewhere in the Northumberland and Lambert formations on Vancouver Island which Ushur (1952, p. 19, 27, 34, 40) correlates with the lower part of the European Maestrichtian stage. His correlation appears to be based mainly on the smoothness of the adult shells of the pachydiscid ammonites, on the abundance of uncoiled ammonites, and on comparisons with the described ammonites from the Navarro group of Texas and from the late Cretaceous beds of various areas bordering the Pacific Ocean.

On the basis of the ammonite genera present, the Northumberland and Lambert formations can just as reasonably be correlated with the Campanian as with the Maestrichtian stage. An age determination based on smoothness of adult pachydiscid ammonites seems risky considering how little is actually known about the family. Comparisons with the ammonites of the Navarro group merely reflect the fact that many of the ammonites of the Navarro are described whereas most of the ammonites of the Taylor group and Austin chalk are undescribed. Comparisons with the latest Cretaceous ammonite assemblages in southernmost South America, Antarctica, and India are of little value insofar as exact correlations with the Campanian or Maestrichtian stages are concerned, because the latest Cretaceous in those areas has not been studied in any detail. The ammonite collections have been made mainly with respect to gross lithologic units. In fact the reported occurrence of certain species of ammonites from several different formations, some of which are separated by unconformities, suggests that some of the collections have been mixed. In Japan where considerable detailed stratigraphic work has been done, the Japanese paleontologists admit their inability to make exact correlations with the European stages above the Coniacian (Matumoto, 1943, p. 229–230). It seems evident that much more paleontological and stratigraphical work is needed dealing with the Cretaceous rocks exposed in areas bordering the Pacific Ocean before many positive correlations can be made with the European stages.

The highest fossils obtained from the Matanuska formation are from the upper third of the shale member. They include *Pachydiscus*, a large, round, flat weakly ornamented *Inoceramus* similar to *I. sagensis* Owen, and an elongate, fairly strongly ribbed *Inoceramus* similar to *I. simpsoni* Meek or to *I. barabini* Meek (not Morton). These species of *Inoceramus* in the western interior of the United States occur in the upper part of the Pierre shale in beds of late Campanian to early Maestrichtian age.

In summation, the Matanuska formation is equivalent to at least the Coniacian to Campanian stages of Europe. The highest beds may be Maestrichtian. There is no evidence that the basal beds are older than Coniacian.

17. The Nelchina limestone, according to information furnished by Arthur Grantz of the Geological Survey, is sandy, ranges from 30 to 170 feet or more in thickness, rests locally with conformity on 100 to 200 feet of conglomerate and sandstone, and is overlain by about 100 feet of soft shale and sandstone. The underlying conglomerate and sandstone contains innumerable well-preserved specimens of *Aucella crassa* Keyserling and *Aucella crassicollis* Keyserling. The latter species is characteristic of the Valanginian in the Boreal

region and is reported to reach its maximum abundance during the middle Valanginian. An age not younger than Valanginian for the limestone is indicated by the presence of the deeply grooved belemnite genus *Belemnopsis* on the surface of the limestone and in an immediately overlying sandstone.

18. Ammonites of Late Cretaceous age, probably Campanian, have been found at Cape Kaguyak on the Shelikof Strait in the upper part of a sequence consisting of about 400 feet of black siltstone and thin beds of limestone overlying the Naknek formation (Hazzard, 1950, p. 227). The ammonites include *Pachydiscus* cf. *P. ootacodensis* Stoliczka, *P. suciaensis* (Meek), *Phylloceras ramosum* Meek, *Gaudryceras* cf. *G. denmanense* Whiteaves, and *Diplomoceras notabile* Whiteaves. With these is one specimen of *Inoceramus* that is probably an immature form of *I. subundatus* Meek. The same assemblage has been found, also, about 7 miles southeast of the mouth of the Kamishak River. These ammonites and the *Inoceramus* are identical with species in the upper third of the Matanuska formation of the Cook Inlet district, Alaska, and with species from Vancouver Island and near-by islands described by Whiteaves (1879; 1903), Meek (1876), and Usher (1952). In the Matanuska formation these species occur many hundreds of feet above beds containing *Inoceramus undulatoplicatus* Roemer, which occurs nearly worldwide at the base of the Santonian. Therefore, stratigraphic position alone shows that the faunule is younger than lower Santonian. In Vancouver Island these species occur in the Lambert formation and the lower part of the Northumberland formation and are dated by Usher (1952, p. 19, 27, 34, 39) as Maestrichtian. A similar faunule from Lower California was described by Anderson and Hanna (1935) and was reported by them (1935, p. 16, 17) to be widespread in California in the upper part of the Panoche formation, which they correlated with the Campanian.

19. The Chignik formation near Chignik Bay and Herendeen Bay consists of 600 to 800 feet of sandstone, shale, conglomerate, and coal that was deposited during only a small part of Late Cretaceous time. Determination of its age is based mainly on the presence throughout of the coarsely plicate *Inoceramus undulatoplicatus* Roemer, a species which occurs world-wide near the Coniacian and Santonian boundary. Of possible age significance is the presence near the top of the Chignik formation of a large specimen of *Pachydiscus* (Mes. loc. 5580) that is identical with *P. multisulcatus* (Whiteaves) (1903, p. 349, Pl. 50; Ushur, 1952, p. 81, Pl. 16, figs. 1–4; Pl. 31, fig. 8) from the Nanaimo group of Vancouver Island. On Vancouver Island it occurs in the Qualicum formation which Ushur (1952, p. 7, 22, 38) correlates with the lower part of the Campanian on the basis of stratigraphic position. The presence in the Qualicum formation of strongly plicate *Inoceramus* similar to, or identical with, *I. undulatoplicatus* Roemer suggests, however, that the formation may not be younger than Santonian.

20. The Herendeen limestone of Herendeen Bay and Port Moller is correlated with the lower and middle Valanginian because it contains numerous well-preserved specimens of *Aucella crassicollis* Keyserling. There is no faunal evidence that it includes rocks of Berriasian age. It rests concordantly on the Staniukovich shale, which contains aucellas with narrow, elongate umbones comparable with *A. piochii* Gabb. This type of *Aucella* is characteristic of Portlandian beds in California and northern Eurasia and has not been found anywhere in Alaska associated with aucellas of Early Cretaceous age. Mesozoic collection 5572 (Martin, 1926, p. 292), which Atwood (1911, p. 40) could not locate for certain stratigraphically because of a thick snow cover, contains the same type of *Aucella* as found elsewhere in the Staniukovich shale. In addition it contains a few small, plump aucellas that Stanton (*In* Martin, 1926, p. 295) compared with *A. crassicollis* Keyserling but which can be matched better in the Russian Portlandian by such a species as *A. subinflata* Pavlow (1907, p. 67, Pl. 6, figs. 1–4) or in the Berriasian by *A. inflata* Toula (Pavlow, 1907, p. 68, Pl. 6, figs. 5a–c). At least, these aucellas lack the swollen umbones and prominent constrictions that characterize *A. crassicollis* Keyserling. Another collection (Mes. loc. 5587) that Atwood considered to belong in the Herendeen limestone contains ammonites and *Inoceramus* of Late Cretaceous age and prob-

ably was obtained from the basal part of the Chignik formation.

21. The upper part of the Lower Cretaceous is probably represented in the Nutzotin Mountains by 300 to 1000 feet, or more, of conglomerate, sandstone, shale, tuff, lava flows, and locally lignitic coal (Capps, 1916, p. 53–57; Moffit, 1943, p. 127–129) that are less indurated and less folded than the underlying basal Cretaceous (Valanginian) or Jurassic rocks. Plant fossils from these higher beds were once identified by F. H. Knowlton as probably Tertiary (Capps, 1916, p. 57) and later by Roland Brown (Moffit, 1943, p. 128) as Upper Cretaceous. However, one collection (Plant loc. 8908) according to determinations by Brown contains *Sequoia reichenbachi* (Geinitz) Heer, which occurs in beds of Albian age in the Yukon region (*see* Annotation 31), and *Cladophlebis septentrionalis* Hollick, which occurs in beds of Coniacian to Santonian age on the Alaska Peninsula (*see* Annotation 19). Another collection (Plant loc. 6806) according to Brown contains *Gleichenia nordenskioldi* Heer, a species originally found in the Kome beds of west Greenland. The Kome beds contain many species in common with the Kootenai formation of Montana and the Lower Blairmore formation of Canada and are probably mostly of Aptian age (*see* Annotation 10). Most of the evidence, therefore, points to an Early Cretaceous age that is approximately the same as that of the Cantwell formation of the Alaskan Range and the Shaktolik group of the lower Yukon region.

22. A thick sequence of black shale and graywacke exposed near the Chisana and White rivers in the Nutzotin Mountains has furnished a few specimens of *Aucella crassicollis* Keyserling and *A. sublaevis* Keyserling (Mes. locs. 8807, 8808, 8810, 18339), which species occur in the Valanginian of the Boreal region. The aucellas from Mes. locs. 8811 and 18349 resemble *A. piochii* Gabb and are probably of late Jurassic age, younger than the Naknek formation.

23. The Cantwell formation consists of several thousand feet of continental deposits and some interbedded lavas and graywacke. It is well indurated but is metamorphosed only near fault zones. It rests with probable unconformity on slates and graywackes that have furnished fossils of Late Jurassic and earliest Cretaceous age. (*See* Annotation 24.) It is overlain by several thousand feet of continental Eocene strata that are much softer and less faulted and folded (Capps, 1940, p. 112–118) and have furnished many plant fossils.

The age of the Cantwell formation for many years was considered as probably Eocene on the basis of a few fragmentary plants. In 1936, however, Ralph W. Chaney accompanied S. R. Capps to a fossil locality (Plant loc. 7278) and collected eight species that are characteristic of the Cretaceous flora of Alaska (Capps, 1940, p. 118; R. W. Chaney, memorandum of Jan. 30, 1937). The species identified by Chaney are as follows:

1. *Podozamites lanceolatus* Braun
2. *Cephalotaxopsis microphylla laxa* Hollick
3. *Sequoia obovata* Knowlton
4. *Populites mirabilis* Hollick
5. *Castaliites ordinarius* Hollick
6. *Credneria inordinata* Hollick
7. *Pseudoprotophyllum dentatum* Hollick
8. *Zizyphus electilis* Hollick

Among the above species, *Sequoia obovata* and *Zizyphus electilis* occur elsewhere in Alaska in the Chignik formation of the Alaska Peninsula. This formation on the basis of its mollusks is of late Coniacian to early Santonian age. (*See* Annotation 19.) The other species listed are common in the lower Yukon region in either the Melozi formation, or the Kaltag formation, or in both. *Podozamites lanceolatus* occurs also in the Nulato formation, which lies between the Melozi and Kaltag formations and is dated on the basis of the ammonite *Gastroplites* as middle Albian.

Assignment of the Cantwell formation to the Albian agrees with the field observations that the formation was subjected to considerable orogenic movements before the overlying continental beds of Eocene age were deposited.

24. Part of the thick sequence of slate and graywacke underlying the Cantwell formation has been assigned previously to Late Cretaceous age on the basis of two crushed fragments of *Inoceramus* (Mes. locs. 10124, 10125) obtained on Long Creek in the Yentna district. These fragments represent a large, compressed species of *Inoceramus*, which kind occurs commonly in the Upper Cretaceous but is also known in the Lower Cretaceous and in the Jurassic.

Such fragments generally have little significance for close age determinations.

The Valanginian is represented at least locally in the slate and graywacke sequence cropping out on the flank of the Alaska Range. One fossil collection (Mes. loc. 15414) made by Capps (1933, p. 260–264; 1940, p. 111) from the West Fork of the Chulitna River contains some crushed aucellas that probably belong to *Aucella crassicollis* Keyserling. At least one specimen has the umbonal swelling and pronounced constriction that characterizes that species, and several other specimens have the irregular, thick concentric ribs that are common in aucellas of Valanginian age.

Beds of supposed Valanginian age in the eastern part of the Alaska Range in the Suslota Pass district (Moffitt, 1933, p. 154) are in part at least incorrectly identified. The aucellas from Mesozoic locality 16085 belong to *A. rugosa* (Fischer) which ranges from the middle Kimmeridgian to the basal Portlandian. The *Aucella* from Mesozoic locality 16259 is an indeterminable right valve that might be either Late Jurassic or Early Cretaceous in age.

25. Several thousand feet of continental rocks exposed on the banks of the Yukon River near Seventymile River have furnished plant fossils that are reported to be partly Upper Cretaceous and partly Eocene (Mertie, 1930, p. 141–146; Hollick, 1930, p. 18, 19, 34; 1936, p. 31). The Cretaceous plants indicate a correlation with the Kaltag and Melozi formations of the lower Yukon region, which are of Albian age, although the Kaltag possibly extends into the Cenomanian.

26. Only the Berriasian and Valanginian stages of the Lower Cretaceous have been identified in collections from the Kandik formation in the Eagle district (Mertie, 1930, p. 136–141). The Berriasian is represented by *Aucella okensis* Pavlow at Mes. loc. 2674. The Valanginian is represented by *Aucella sublaevis* Keyserling at Mes. locs. 3785 and 13429.

27. The presence of middle Albian in the Wolverine Mountain area in the Hot Springs–Rampart districts is proven by the presence of many specimens of the ammonites *Cleoniceras* from Mes. locs. 4278, 4279, and 8900 and *Gastroplites* at Mes. locs. 4278 and 4280. The species at loc. 4280 is similar to *G. spiekeri* McLearn. Previous reference to the Upper Cretaceous of the beds containing these fossils was based mainly on erroneous identification of the mollusks and on the insistence of botanists that the plants were of early Late Cretaceous age (Martin, 1926, p. 392–394; Mertie, 1937, p. 166–170).

28. Earliest Cretaceous not younger than Valanginian is possibly represented in the Hot Springs–Rampart districts, as indicated by some small aucellas (Mes. locs. 11390, 11391, 15981) similar to *A. sublaevis* Keyserling. The preservation of the aucellas does not permit a positive identification, but their plump shape suggests an early Cretaceous rather than a Jurassic age.

29. A thick sequence of sandstone, shale, conglomerate, and limestone exposed in the lower part of the Koyukuk Valley below the Kateel River resembles the Shaktolik group of the lower Yukon and is identified with that group on the basis of a few plants (Martin, 1926, p. 444–446; Martin *in* Hollick, 1930, p. 32, 33). A similar sequence of rocks in the upper part of the Koyukuk Valley has been called the Bergman group (Schrader, 1904, p. 77, 78; Martin, 1926, p. 446–448). It has furnished species of *Lemuroceras* (Mes. loc. 24678) and *Aucellina* (Mes. locs. 24679, 24680) identical with species in the upper part of the Torok formation in northern Alaska and is therefore considered of lower Albian age.

30. The Koyukuk group (Martin, 1926, p. 442–444) has furnished aucellas of Valanginian age including *A. sublaevis* Keyserling (Mes. loc. 2180, 24686) and *A. crassicollis* Keyserling (Mes. locs. 2178, 2181, 24685).

31. The 8000 to 10,000 feet or more of sedimentary rocks constituting the Shaktolik group in the lower Yukon Valley has previously been referred to the lower part of the Upper Cretaceous mainly on the basis of plant fossils (Martin, 1926, p. 424–429; Hollick, 1930, p. 5–8; Martin *in* Hollick, 1930, p. 31, 32). This age determination has been based on the identity of many species with species in the Dakota sandstone. In addition 3 species have been recorded previously from the Raritan formation (Cenomanian), and 5 from the Magothy formation (Coniacian) of the Atlantic Coast. Also, 2 species have been recorded from the Laramie formation. The age evidence

indicated by these species from the Magothy and Laramie formations has been more than balanced by the presence of 12 species of Early Cretaceous age, even though Hollick (1930, p. 5) does not state what stages of the Lower Cretaceous are represented. In general, therefore, assignment of the plant-bearing beds of the Shaktolik group to the early Late Cretaceous has seemed reasonable under the assumption that the Dakota sandstone is of Cenomanian age. This assignment has been partially supported by preliminary determinations of the marine mollusks by Stanton (Martin, 1926, p. 412–416).

Recent studies of marine mollusks confirm the correlation of the Shaktolik group with the plant-bearing parts of the Dakota sandstone of Kansas, Iowa, South Dakota, and North Dakota but shows that both the Shaktolik group and the Dakota sandstone in the States mentioned are of Albian rather than Cenomanian age. This age determination is based mainly on the presence of the ammonite *Gastroplites* in the Nulato formation (Mes. locs. 2678, 2926, 2927, 21418) of the Shaktolik group and of *Neogastroplites* in the Mowry shale which overlies the Dakota sandstone. The significance of the ammonites in the Mowry shale in the United States has been discussed by Cobban and Reeside (1951, p. 1892, 1893). *Gastroplites* in England has been found at the top of the middle Albian (Spath, 1937, p. 257–260). *Gastroplites* in California is probably represented by *Sonneratia crossi* Anderson and *S. stantoni* Anderson (Anderson, 1938, p. 196) which occur near the top of the Horsetown formation associated with other ammonites of middle Albian age. The position of *Neogastroplites* in the Mowry shale cannot be lower than upper Albian because the Mowry overlies the Skull Creek shale which is in part the northern extension of the Kiowa shale of Kansas and the Kiamichi formation of Texas, both of which contain late middle Albian ammonites. The position of *Neogastroplites* is definitely above that of *Gastroplites* in the western interior of Canada McLearn, 1945, p. 11, Fig. 1). In Canada *Neogastroplites* has been dated tentatively as late Albian on the basis of stratigraphic position, but the possibility of its ranging into the Cenomanian cannot be excluded. However, in the United States the entire Cenomanian seems to be present in the beds overlying the Mowry shale (Cobban and Reeside, 1951, p. 1893; Cobban, 1951a, p. 2197). At most, *Neogastroplites* could not be younger than early Cenomanian.

Concerning the age of the Shaktolik group, therefore, the presence of *Gastroplites* in the Nulato formation is evidence that that formation is not younger than middle Albian. The species present, *G.* aff. *G. allani* McLearn (Mes. locs. 2926, 2927, 21418) and *G. stantoni* McLearn (not Anderson) (Mes. loc. 2678), resemble species from California and northern Alaska that are of early middle Albian age (*see* annotations 1, 14, 46). Such an age is also indicated by two ammonites probably belonging to *Cleoniceras* (Mes. loc. 21418), which genus is not known above the early middle Albian. As the adjoining Melozi and Kaltag formations contain many plant species in common, they are probably about the same age as the Nulato formation. The reported thickness of the Kaltag formation is so much less than the Nulato that it probably does not represent as much time and may not be younger than the middle Albian. Likewise the Melozi formation probably represents only a small part of the middle Albian. This is indicated by the fact that its flora is quite distinct from that in the *Lemuroceras* beds in the lower part of the Kennicott formation of the Chitina Valley (*see* Annotation 14) or in the *Lemuroceras*-bearing Torok formation of northern Alaska. The *Lemuroceras* beds have furnished a variety of mollusks which can be dated confidently as lower Albian to early middle Albian. Considering that the plants in the *Lemuroceras* beds have been compared by paleobotanists with Jurassic and earliest Cretaceous plants of California and other areas, there must have been a marked change in the Alaskan flora during middle Albian time.

32. The Ungalik conglomerate comprises several thousand feet of conglomeratic beds, appears to underlie the Shaktolik group conformably and is considered to be of about the same age (Martin, 1926, p. 412), although it has not furnished determinable fossils. Until the formation has been more thoroughly studied, the possibility exists that it may be at

least partly of Neocomian age, as such strata have been identified to the north in the Koyukuk Valley and to the southwest in the Kuskokwim region.

33. The presence of beds corresponding to the Coniacian stage of the middle Late Cretaceous is based on a collection of *Inoceramus vancouverensis* Shumard from the northwest side of the Innoko River about 30 miles airline above the confluence of the Innoko and Iditarod rivers (Mes. loc. 13430). The age significance of this species is discussed under Annotation 35.

34. There is no reliable fossil evidence for the age of thousands of feet of sandstone and shale overlying the Paleozoic rocks in the Innoko and Iditarod valleys and in the upper Kuskokwim Valley. Some specimens of *Inoceramus* from these beds are too poorly preserved for specific identification. The apparent radial folds on specimens from Mes. loc. 7823 could be a result of crushing. One collection (Mes. loc. 12561) obtained near the head of the Nowitna River on the southern margin of the Ruby district contains a number of belemnites and fragments of a large species of *Inoceramus*. The presence of belemnites suggests that the beds containing them are of Early Cretaceous or Jurassic age because belemnites are rare in the Upper Cretaceous of Alaska and in the western interior of North America. The presence of a large species of *Inoceramus* suggests an Albian or later Cretaceous age, although a few large *Inoceramus* have been found in the Upper Jurassic of North America.

35. Upper Cretaceous graywacke and siltstone estimated to be between 30,000 to 65,000 feet thick cover large areas in the Kuskokwim region as far northeast as the Stony River in the Georgetown district (Personal communication from J. M. Hoare and W. M. Cady). These rocks have furnished many *Inoceramus* and a few ammonites that prove that the Cenomanian and Coniacian stages are represented. Some of the species of *Inoceramus* may represent the Turonian or Santonian stages. The *Inoceramus* of Coniacian age occur mostly in sediments interbedded with andesitic volcanics in the lower part of the Kuskokwim region.

The Cenomanian is represented by *Inoceramus dunveganensis* McLearn (Mes. locs. 9087, 18646, 18866, 19390, 19732) and *I. athabaskensis* McLearn (Mes. loc. 19388 and probably 18928 and 19392). *I. dunveganensis* has been found elsewhere in the Dunvegan formation of Alberta and British Columbia (McLearn, 1945, p. 3). *I. athabaskensis* occurs in both the Dunvegan formation and in the basal part of the slightly younger La Biche formation below beds containing the ammonite *Watinoceras* and *Inoceramus labiatus* Schlotheim of early Turonian age (McLearn, 1943, p. 37, 44). An association of *I. nahwisi* McLearn with *I. athabaskensis* at Mes. loc. 19388 is interesting because *I. nahwisi* has been reported previously only from the *Neogastroplites* beds of Canada (McLearn, 1945, p. 11, 12) and the United States (Cobban, 1951a, p. 2181). These *Neogastroplites* beds are either of latest Albian or early Cenomanian age and are distinctly older than the Dunvegan formation. The Cenomanian age of the Dunvegan formation is based not only on its stratigraphic position but on the presence of species of the ammonite *Dunveganoceras* identical with species in the lower part of the Greenhorn formation of the United States whose age is well established.

Some of the species of *Inoceramus* from the Kuskokwim region might be either Cenomanian or Turonian. One species (Mes. locs. 9226 and 18926) is similar to *I. reachensis* Etheridge (Woods, 1911, p. 278, Pl. 48, figs. 4, 5; Pl. 49, fig. 1) from the Cenomanian of England. It is associated with *Scaphites* (Mes. loc. 18926) having evolute septate coils which occur in beds ranging in age from late Albian to early Turonian and do not occur again until near the end of the Cretaceous. Another species of *Inoceramus* (Mes. loc. 20718) is similar to *I. corpulentus* McLearn which occurs in the Dunvegan formation and the younger Kaskapau and Blackstone formations of Alberta and British Columbia. Most of its reported occurrences are from beds of Turonian age.

The Coniacian stage is almost certainly represented by *Inoceramus* cf. *I. uwajimensis* Yehara and an associated ammonite *Parapuzosia* (Mes. loc. 20717). The *Inoceramus* is identical with a species in the lower few hundred feet of the Matanuska formation, which has furnished considerable evidence for a Coniacian

age (*see* Annotation 15). The Coniacian stage is probably also represented by *Inoceramus vancouverensis* Shumard (Whiteaves, 1879, p. 170, Pl. 20, figs. 4, 4a, b) (Mes. locs. 13430, 20716, 21033, 21481) and by an associated ammonite *Scaphites* cf. *S. impendicostatus* Cobban (Mes. loc. 20716). The latter species (Cobban, 1951b, p. 28, Pl. 11, figs. 1–14) is characterized by peculiar flattened, somewhat overhanging ribs on the sutured part of its shell, a feature unknown in any other species of *Scaphites*. It occurs in rocks equivalent to the basal part of the Niobrara formation which can be correlated definitely with the basal part of the Coniacian stage.

Some evidence concerning the age of *Inoceramus vancouverensis* Shumard is shown by its occurrence in the southern part of Vancouver Island near the base of the Nanaimo group in the same coal-bearing sequence that has furnished *Inoceramus undulatoplicatus* Roemer (Whiteaves, 1879, p. 168, 171; 1903, p. 348, 351, 397). The fossil-bearing part of this sequence is now included in the Haslam formation (Ushur, 1952, p. 9–11) and is correlated by Ushur (1952, p. 36–38) with the Campanian stage, with reservations. Of the ammonites present *Pseudoschloenbachia* indicates an age not older than Santonian, *Hauericeras* and *Canadoceras* indicate an age not older than the Coniacian, and the species present are comparable to species of Coniacian to Campanian age in other parts of the world. Six of the species of ammonites range up into younger formations, but the range of the species within the Haslam formation is not discussed (Ushur, 1952, p. 37). Ushur did not mention the age significance of *Inoceramus undulatoplicatus* as a nearly world-wide marker near the Coniacian-Santonian boundary. A suggestion that *Inoceramus vancouverensis* actually underlies *I. undulatoplicatus* within the Haslam formation is furnished in a statement by Ushur (1952, p. 11) that

> "*Inoceramus* cf. *schmidti* is found abundantly on Brannen Creek and from the upper part of the formation between Nanoose Bay and Blunden Point, and *I.* ex gr. *subundatus* Meek is common in most other parts of the formation."

Concerning this statement, it is inferred that *Inoceramus* cf. *schmidti* is identical with *Inoceramus undulatoplicatus* Roemer and that *I.* ex gr. *subundatus* includes *I. vancouverensis* Shumard. If the superposition of *I. undulatoplicatus* over *I. vancouverensis* is valid, then the Haslam formation probably includes beds of Coniacian age. It is probably significant that species similar to *I. vancouverensis* in the Western Interior and in the Gulf region of the United States occur at a lower level than *I. undulatoplicatus*, in beds that are correlated with the lower Coniacian.

The volcanics and associated sediments that are herein considered of Coniacian age are reported by Joseph Hoare (Personal communication dated March 4, 1953) to rest with probable unconformity on rocks of Cenomanian age.

Upper Cretaceous sedimentary rocks younger than the Coniacian may exist in the central Kuskokwim region, but the faunal and stratigraphic evidence is meager.

36. The Albian is probably represented in the lower Kuskokwim region by thick masses of conglomerate that are interbedded with and grade laterally into graywacke and siltstone. These conglomeratic sediments overlie beds of Valanginian age and are overlain by beds of Cenomanian or locally of Coniacian age. The evidence for an Albian age consists mainly of a small species of *Inoceramus* (Mes. locs. 21476 and 19395B) characterized by an extended posterior wing, prominent concentric ribbing of approximately equal strength, and a weak sulcus on its posterior side. The ribbing is rather similar to that of *I. neocomiensis* d'Orbigny (1846, p. 503, Pl. 303, figs. 1, 2; Woods, 1911, p. 262, Pl. 45, figs. 1, 2) or of *I. ewaldi* Schlüter (Wollemann, 1906, p. 272, Pl. 6, fig. 9) from the Aptian and lower Albian of northwest Europe. The extended posterior wing is similar to that on *I. neocomiensis* var. *alata* Schmidt (1872, p. 160, Pl. 3, figs. 9a, b; Fig. 10a, b) from northern Siberia. None of these Eurasian forms have a sulcus on the posterior side.

The Albian age of the species of *Inoceramus* in question from the lower Kuskokwim is based on probable identity with a specimen from northern Alaska at Mes. loc. 20399 at the top of the Lower Cretaceous sequence. This specimen is associated with *Inoceramus anglicus* Woods, a middle and upper Albian marker. It is in a lithologic unit whose upper

part has furnished *Gastroplites* and *Cleoniceras* and is correlated with the lower part of the middle Albian substage.

37. Beds of Valanginian age have been identified faunally in the lower and central Kuskokwim region west of the Holitna Valley in the upper part of 15,000 feet, or more of graywacke, siltstone, chert, volcanics, and very minor amounts of limestone. The evidence consists of *Aucella crassicollis* Keyserling (Mes. locs. 19730, 21473, 23166), *A.* cf. *A. crassicollis* Keyserling (Mes. locs. 21474, 21475, 23163, 23167, 23169), and *A. sublaevis* Keyserling (Mes. loc. 23171). The Berriasian has not been identified. The underlying beds include Upper Jurassic at least locally, because at one place (Mes. loc. 20714) about 28 miles S.8° W. of Aniak in the Akiak District were obtained specimens of *Aucella mosquensis* (von Buch) and *A. rugosa* (Fischer). Much of the thick sequence below the Valanginian is of Late Triassic age. In places the Cretaceous strata rest on gneiss and schist that are probably Precambrian, or at least much older than near-by exposures of Devonian limestone (Personal communication from J. M. Hoare, Dec. 5, 1952).

38. An enormous thickness of beds in the Nushagak Valley and Nushagak Hills has been mapped by Mertie (1938, p. 48–61) as probably Cretaceous, although the paleontologic evidence consists only of a few fragments of interdeterminable *Inoceramus*. The presence of Upper Creatceous strata has been established, however, by Wallace M. Cady by actual tracing from the central Kuskokwim Valley southward into the valleys of the Nushagak and Mulchatna rivers (Personal communication from W. M. Cady).

39. The presence of the Bergman group in the Kobuk Valley of northern Alaska is based on mapping westward from the upper part of the Koyukuk Valley (Mendenhall, 1902, p. 39–42; Smith, 1913, p. 284–286) and not on fossil evidence.

40. Not much more is known about the Cretaceous sequence on Cape Lisburne than was summarized by Martin in 1926 (p. 455–467). Recently geologists mapping in the western part of the Wainwright district have noted that the upper part of the Torok formation and the Nanushuk group become less marine westward toward Cape Lisburne, as shown by a decrease in the number of marine organisms, an increase in plant-bearing beds, and by lithologic changes. Aerial photographs indicate that beds equivalent to the Torok and Nanushuk are present in the northern part of Cape Lisburne, but the exact correlation of these units with the Corwin formation as described by Schrader (1902, p. 244, 245; 1904, p. 72–74) and Collier (1906, p. 16, 27–30, 36–42) is not known. Certainly some of the plants from the Corwin formation (Martin, 1926, p. 461) indicate a correlation with the lower part of the Kennicott formation of the Chitina Valley. This part contains many ammonites and pelecypods of early to middle Albian age that are identical with or similar to species in the Torok formation of northern Alaska.

41. The Valanginian has been identified on the Kivalina River in the southern part of Cape Lisburne on the basis of *Aucella sublaevis* Keyserling (Mes. loc. 13716). The beds in which these fossils occur are a southwestward continuation of the Okpikruak formation in the De Long Mountains.

42. The term "Nanushuk group, undifferentiated," is useful in areas that have not been thoroughly studied or in which outcrops are few. In such areas the lithological characteristics of the group are essentially the same as in the foothills of the Brooks Range between the Killik and Anaktuvuk valleys.

43. The middle and upper parts of the Torok formation have furnished Albian ammonites belonging to *Lemuroceras*, *Cleoniceras*, and *Beudanticeras*. *Beudanticeras* has been found at seven localities and is associated with *Lemuroceras* at one locality and with *Cleoniceras* at one. *Cleoniceras* has been found at eight localities, and *Lemuroceras* at eight localities. *Lemuroceras* has not been found with *Cleoniceras*, although the stratigraphic positions of the various collections show that the lowest occurrence of *Cleoniceras* is below the highest occurrence of *Lemuroceras*. Besides these ammonites, the only other fossil of known stratigraphic significance is the pelecypod *Aucellina dowlingi* McLearn which occurs in the upper part of the Torok formation some 1500 feet above the lowest occurrence of *Lemuroceras*.

The Torok formation is dated as early Albian because it underlies beds that are probably not younger than early middle Albian and because it contains *Lemuroceras* and *Aucellina* similar to species in the lower part of the Kennicott formation of the Chitina Valley. This part can be correlated with certain zones in the upper part of the Horsetown formation of California (*see* Annotation 14). Judging from the distribution of *Lemuroceras* in the Kennicott and Horsetown formations, it ranges from the top of the lower Albian (zone of *Leymeriella tardefurcata*) into the lower part of the middle Albian (zone of *Douvilleiceras mammillatum*) but is most common in the lower Albian. *Cleoniceras* has the same known range but is most common at the top of the *Leymeriella tardefurcata* zone, according to Spath (1943, p. 687, 699). In Madagascar (Collignon, 1949, p. 102, 109) *Cleoniceras* and *Lemuroceras* are associated in beds correlated with the *Douvilleiceras mammillatum* zone, but *Lemuroceras* is more common than *Cleoniceras*. In northern Alaska *Cleoniceras* ranges into and becomes fairly common in the Tuktu member of the Umiat formation, in which *Lemuroceras* has not been found. This common nonassociation of the two genera suggests that they occupied slightly different ecological niches and that either genus may be abundant locally during late lower Albian and early middle Albian. Considering that the time represented is only a small part of the Albian stage, it is interesting that the Torok formation ranges in thickness from 6000 to 10,500 feet and the Tuktu member of the Umiat formation from 1000 to 2500 feet in the area between the Killik and Anaktuvuk rivers.

It is doubtful whether the Torok formation includes beds older than Albian. In some sections the basal part of the Torok has not furnished fossils, but, considering the rapidity of sedimentation, this part need not represent more than the zone of *Acanthohoplites nodosocostatus* of the basal Albian of Europe.

The Torok formation thins eastward from the Sagavanirktok Valley to the Shaviovik Valley and is absent east of the latter. This thinning is ascribed to onlap against a structural high in the area between the Shaviovik and Sadlerochit valleys (Personal communication from A. S. Keller and R. L. Detterman).

44. On the basis of aucellas identical with species in northern Eurasia, the Okpikruak formation corresponds with the Berriasian and Valanginian stages. Its basal few hundred feet includes *Aucella okensis* Pavlow and *A. subokensis* Pavlow, which are characteristic of the beds at the Jurassic-Cretaceous boundary. With these are species that probably belong to *A. terebratuloides* Lahusen and *A. surensis* Pavlow. Both of these range from the latest Jurassic into the Berriasian but are more common in the latter.

Most of the Okpikruak formation is of Valanginian age. Above the beds characterized by *A. okensis* and *A. subokensis* occur numerous *A. sublaevis* Keyserling. With these may be associated *A. crassa* Pavlow, or rarely *A. crassicollis* Keyserling. The latter, however, is more common at higher levels in the middle and upper parts of the formation. As *A. crassicollis* is reported to attain its greatest abundance in the middle Valanginian (Pavlow, 1907, p. 77), the beds in northern Alaska having abundant *A. sublaevis* are probably lower Valanginian.

There is no faunal evidence in all of Alaska for the presence of rocks representing the Hauterivian, Barremian and Aptian stages, although the Aptian may be represented locally in the Torok formation beneath beds containing *Lemuroceras* and *Cleoniceras*. During these stages Alaska was emergent and was subjected at least locally to mountain-building movements before Albian time. Orogeny culminated probably during the Barremian because, as noted by Maync (1949, p. 242), there is no evidence for the presence of the Hauterivian or Barremian stages anywhere in the Arctic region. By Aptian time, however, the seas were again encroaching on the lands, as shown by the presence of beds of that age in East Greenland (Frebold, 1935; Maync, 1949, p. 258–270) and in Spitzbergen (Frebold and Stoll, 1937, p. 75, 76). Possibly the shrinking of the Arctic Ocean during the Barremian has some bearing on the near extinction of ammonites at that time.

The orogenic movements during Hauterivian and Barremian time resulted in differential erosion of the Okpikruak formation. This is particularly evident in the area between the Sagavanirktok and the Canning valleys where

the formation thins from a maximum of 1560 feet to less than 200 feet and is locally absent (Personal communication from A. S. Keller and R. L. Detterman). The easternmost exposure is about 2 miles west of the Canning River. No trace of the Okpikruak formation has been found along the banks of the Canning River or in the area to the east, although exposures there are excellent. Fossil collections from the Okpikruak formation between the Sagavanirktok and Canning valleys contain mostly *Aucella okensis* Pavlow and *Aucella subokensis* Pavlow of Berriasian age. *Aucella crassicollis* Keyserling was found only at one locality near the Sagavanirktok River. *Aucella sublaevis* Keyserling was found only at two widely separated localities. The fossil evidence indicates, therefore, that the thinning of the Okpikruak formation is due to erosion and not to onlap against a structural high.

45. Correlations of the various members, tongues, and formations of the Colville group are based partly on mollusks and Foraminifera and partly on interpretations of the intertonguing relationships of dominantly nonmarine or brackish-water sequences on the south with mostly normal marine sequences in the Arctic Coastal Plain (Payne, Gryc, Tappan, *et al*, 1951; Gryc, Patton, Payne, 1951, p. 164–167). At the base the Seabee member of the Shrader Bluff formation contains such mollusks as *Scaphites delicatulus* Warren, *Watinoceras*, and *Inoceramus labiatus* (Schlotheim), which are of early Turonian age. The overlying Tuluga member in its lower part contains *Inoceramus lamarcki* var. *cuvieri* Sowerby which in Europe ranges from the middle Turonian through the Coniacian. In its upper part the Tuluga member contains *Inoceramus* similar to *I. lundbreckensis* McLearn and to *I. cardissoides* Goldfuss and species of *Scaphites* which indicate a correlation with the upper part of the Santonian and the lower part of the Campanian stages. The still higher Sentinel Hill member is correlated by means of Foraminifera with the lower part of the Riding Mountain formation of Manitoba and the Lea Park shale of Alberta, which are equivalent to the lower part of the Pierre shale in the western interior of the United States. The Sentinel Hill member is absent in the foothills north of the Brooks Range, probably because of nondeposition.

Unconformities based on physical criteria occur both above and below the Seabee member of the Shrader Bluff formation (Personal communication from Thomas Payne, George Gryc, and R. L. Detterman). The unconformity below the Seabee member cannot represent more than a minor part of the Cenomanian. The unconformity between the Seabee member and the Tuluga member could represent the late Turonian and part of the Coniacian. The fact that marine trangression occurred in western, southwestern, and south-central Alaska in Coniacian time suggests that the initial deposits of the Tuluga member were formed at that time.

46. The Nanushuk group consists of an essentially nonmarine or brackish-water sequence on the south, called the Chandler formation, and a normal marine sequence on the north, called the Umiat formation. These intertongue to some extent in the foothills of the Brooks Range, but particularly in the area near Umiat and along the upper course of Ikpikpuk River.

At the base of the Nanushuk group in the Colville Valley about 1000 feet of marine sandstone, the Tuktu member of the Umiat formation, is assigned to the basal part of the middle Albian because of the presence of *Gastroplites*, *Cleoniceras*, *Inoceramus anglicus* Woods, and *Inoceramus cadottensis* McLearn. *Gastroplites* is represented by only two fragments, but one of those is associated with *Cleoniceras* within the upper 150 feet of the Tuktu member. The *Gastroplites* present, resemble *G. allani* McLearn (1933, p. 18, 19 Pl. 1, figs. 6–8) which occurs in the Western Interior of Canada associated with *Inoceramus cadottensis* in beds somewhat higher than those containing *Lemuroceras*. The range of *Gastroplites* has been discussed under Annotations 1, 14, and 31, and it has been shown that species identical with or similar to *G. allani* and *G. stantoni* McLearn occur in the lower Yukon and in California with other ammonites that have not been recorded above the early middle Albian. The presence of *Cleoniceras* itself is evidence for an age not younger than the early middle Albian. *Inoceramus anglicus* Woods is common in the middle and upper

Albian of the Boreal region. An early middle Albian age for the Tuktu member is based partly on the presence of *Cleoniceras* and *Lemuroceras* in the underlying Torok formation, which indicates an age for that formation not older than the later part of the early Albian.

The Hatbox tongue overlying the Tuktu member ranges from 1000 to 3000 feet in thickness, has furnished plant remains and fresh-water fossils, and is considered entirely nonmarine. There is no field evidence for an unconformity between the Hatbox tongue and the adjoining Tuktu member and Niakogon tongue. On the basis of stratigraphic position the Hatbox tongue represents parts of the middle Albian, all of the upper Albian, and part of the Cenomanian.

At the top of the Nanushuk group in the foothills of the Brooks Range abundant *Inoceramus* have been found in marine intercalations in the Niakogon tongue of the Chandler formation. The common species include *I. athabaskensis* McLearn and *I. dunveganensis* McLearn. These have been identified elsewhere in Alaska in the lower part of the Upper Cretaceous sequence in the Kuskokwim region (*see* Annotation 36). In northwestern Alberta and northeastern British Columbia they are associated with the ammonite *Dunveganoceras* in the Dunvegan formation. *I. athabaskensis* likewise occurs at the base of the La Biche shale on the Athabaska River. All the occurrences in Canada are in beds that underlie the lowest ammonite zone of the Turonian, which zone has been identified in northern Alaska at the base of the Shrader Bluff formation immediately above the Nanushuk group. The stratigraphic position of *Dunveganoceras* in Montana, Canada, and England is upper Cenomanian, according to present information.

47. The Ignek formation comprises two members, according to recent field work by A. S. Keller and R. H. Morris of the U. S. Geological Survey. The lower member consists of a sandstone unit about 200 feet thick and an overlying black shale unit about 260 feet thick. The sandstone unit rests on the Okpikruak formation of Berriasian age 2 miles west of the Canning River and on the Kingak shale of upper Oxfordian age along the Canning River and in Ignek Valley to the east. The sandstone unit contains poorly preserved pelecypods belonging to long-ranging genera. The overlying shale unit contains a microfauna identical with that in the Tuktu member at the base of the Nanushuk group (Personal communication from Harlan Bergquist).

The upper member of the Ignek formation is much thicker than the lower member, contains bentonitic beds, and resembles lithologically parts of the Colville group younger than the Seabee member. It contains a microfauna identical with that in the Tuluga member of of the Colville group (Personal communication from Harlan Bergquist). This correlation is confirmed by the discovery of a squid which Reeside considers identical with *Teusoteuthis longus* Logan from the upper part of the Niobrara formation of Kansas.

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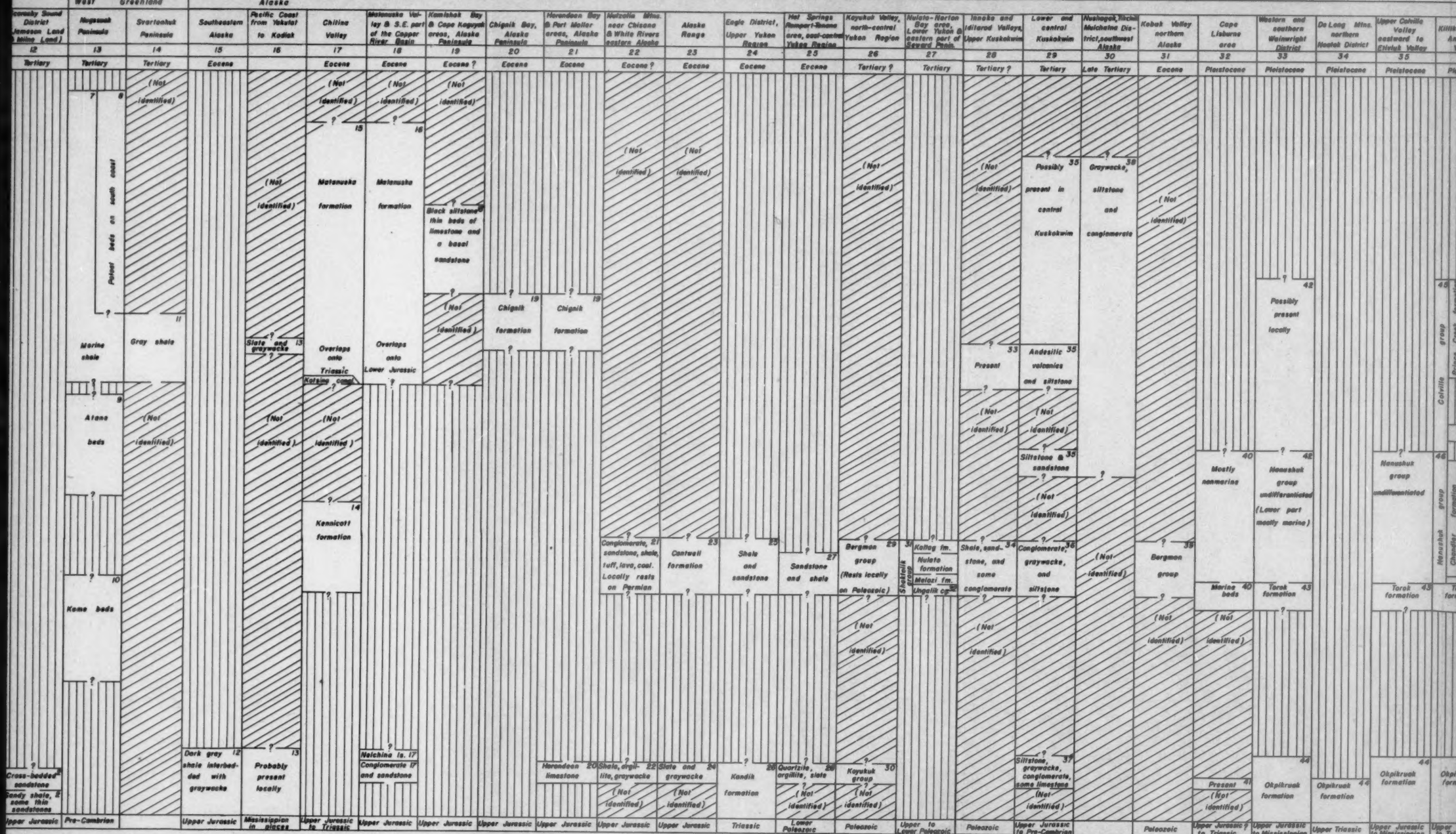
Chart 10 d. - CORRELATION OF THE CRETACEOUS FORMATI

By Ralph W. Imlay and John B. Reeside, Jr

Series	European Stages	Reference sequence for Western Interior	Gulf Coastal Plain	East Greenland: Denmarkshavn in Germania Land (1)	Kelsey Island (2)	Shannon Island (3)	Southwestern Kuhn Island (4)	Northwestern Wollaston Foreland (5)	Southwestern Wollaston Foreland and northeastern Clavering Island (6)	Southeastern Kuhn Island and northcentral Wollaston Foreland (7)	Eastern Wollaston Foreland (Falkenbergt area) (8)	Sabine Island (9)	Hold-with-Hope (10)	Geographical Society Island and Traill Island (11)	Scoresby Sound District (Jameson Land & Milne Land) (12)	West Greenland: Nugssuak Peninsula (13)	Svartenhuk Peninsula (14)	Alaska: Southeastern Alaska (15)	Pacific Coast from Yakutat to Kodiak (16)	Chitina Valley (17)	Matanuska Valley & S.E. part of the Copper River Basin (18)	Kamishak Bay & Cape Kaguyak areas, Alaska Peninsula (19)	Chignik Bay, Alaska Peninsula (20)	Herendeen Bay & Port Moller areas, Alaska Peninsula (21)
Overlying beds							Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Eocene		Eocene	Eocene	Eocene ?	Eocene	Eocene
CRETACEOUS UPPER	Danian ?	Hall Creek formation																							
	Maestrichtian	Fox Hills sandstone	Navarro group	(Not identified)	(Not identified)	(Not identified)								Shale 5		7 8 Point beds on south coast	(Not identified)			(Not identified)	(Not identified)	(Not identified)			
	Campanian	Pierre shale																	(Not identified)	Matanuska formation	Matanuska formation	Black siltstone & thin beds of limestone and a basal sandstone			
	Santonian	Telegraph Creek formation	Austin chalk										Knuds-hoved beds	Shale 5								(Not identified)	Chignik formation	Chignik formation	
	Coniacian	Niobrara formation												(Not identified)		Marine shale	Gray shale		Slate and greywacke 13	Overlaps onto Triassic	Overlaps onto Lower Jurassic				
	Turonian	Carlile shale	Eagle Ford shale											Sandy shale 6		9 Atane beds	(Not identified)		(Not identified)	Katsina cong.					
	Cenomanian	Greenhorn limestone / Belle Fourche shale	Woodbine formation											(Not identified) 6											
			Washita group											Shale 6											
LOWER CRETACEOUS	Albian upper	Mowry shale / Newcastle ss. / Skull Creek sh. / Fall River ss.	Fredericksburg group																						
	Albian middle	Red shale	Trinity group			Present							Black shale 1	Black shale 1	Black shale 1	Black shale, Some sandstone. Many ironstone concretions									
	Albian lower												Pebbly sandstone at base. Overlaps onto Pre-Cretaceous	Black to gray shale 1 Some marl and sandstone.	Black to gray shale 1	Horne Fyreland beds									
	Aptian upper	Dransy limestone / Bechler conglomerate														Mostly yellowish sandstone. Some black shale.									
	Aptian lower	Peterson limestone	Nuevo Leon group	? Present 1 (Not identified)	Sandstone, conglomerate, bone bed limestone and black shale	(Not identified)								? Probably present 1	(Not exposed)	10 Kome beds									
	Barremian	Ephraim conglomerate																							
	Hauterivian		Durango group																						
	Valanginian				Sandstone, gritty conglomeratic ss. 3																				
	Berriasian (Intravalanginian of authors)						Gray sandy shale 2 and yellow sandstone, conglomerate at base	Hiatus beds: Hiatus ss. & lst. 4; Shale, marl & limestone 3; Sandy shale and lenses of limestone 2; Sandy shale 2; Conglomerate & ss. 2	Reddish ss. & silty limestone 4; Young Sound conglomerate & ls. 3; Conglomerate & sandstone 2	Rödryggen beds 4; Albrechts Bay marl & limestone 3	Folkesbury beds (ls., ss., breccia) 3			Present 3	Cross-bedded sandstone 2; Sandy shale, some thin sandstones 2				Dark gray shale interbedded with greywacke 12	Probably present locally 13		Nelchina ls. 17; Conglomerate and sandstone 17		Herendeen limestone 20	Shale, lite, (Ide
Underlying beds				Jurassic	Jurassic or older		Upper Jurassic	Upper Jurassic	Jurassic to Paleozoic	Jurassic	Lower Paleozoic		Triassic	Upper Jurassic	Upper Jurassic	Pre-Cambrian		Upper Jurassic	Mississippian in places	Upper Jurassic to Triassic	Upper Jurassic	Upper Jurassic	Upper Jurassic	Upper Jurassic	Upper

hart 10 d. - CORRELATION OF THE CRETACEOUS FORMATIONS OF GREENLAND AND ALASKA

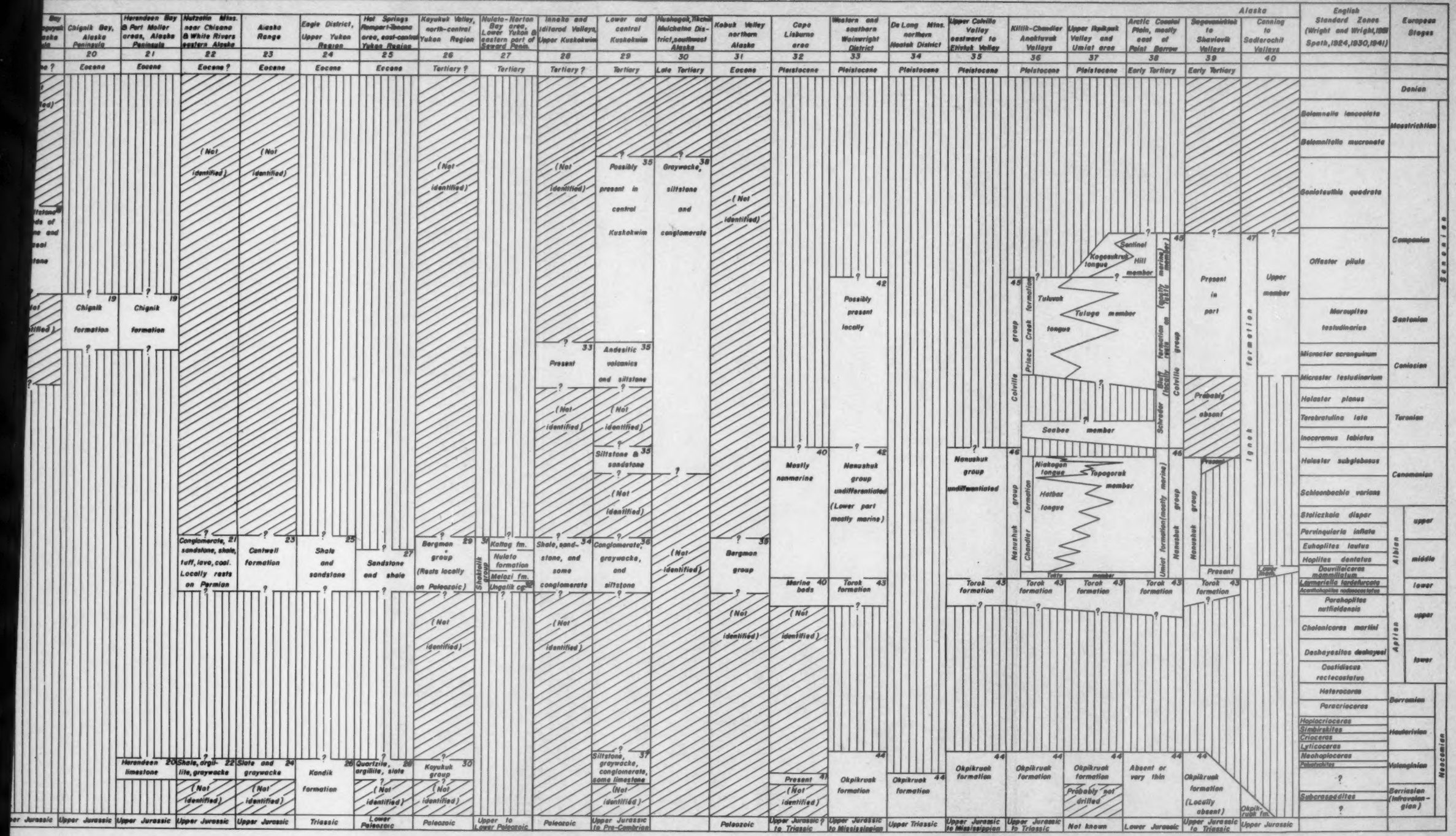
By Ralph W. Imlay and John B. Reeside, Jr.



EOUS FORMATIONS OF GREENLAND AND ALASKA

mlay and John B. Reeside, Jr.

Prepared under the auspices of the Committee on Stratigraphy
of the National Research Council, Carl O. Dunbar, *Chairman*



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CORRELATION OF THE ORDOVICIAN FORMATIONS OF NORTH AMERICA

By the Ordovician Subcommittee of the Committee on Stratigraphy, of the National Research Council, W. H. Twenhofel, *Chairman*, Josiah Bridge, Preston E. Cloud, Jr., Byron N. Cooper, G. Arthur Cooper, E. R. Cumings, James S. Cullison, Carl O. Dunbar, Marshall Kay, Bruce A. Liberty, A. C. McFarlan, John Rodgers, H. B. Whittington, Alice E. Wilson, and Charles W. Wilson, Jr.

With an

Introduction

By Carl O. Dunbar

and a

Discussion of British-American Correlation

By Harry B. Whittington

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Introduction

General Statement

This is Number 2 of a series of correlation charts of North American sedimentary formations prepared by the Committee on Stratigraphy of the National Research Council.[1]

When its preparation was undertaken, some 15 years ago, each member of this subcommittee was asked to collate data for a particular region in which he had personal interest and recognized competence. He was requested to prepare a column for each important outcrop area in his region which would show (1) the current classification of the sedimentary units in that area and (2) the correlations of each of these units with the standard section for the system in North America. These columns were later collated into a first draft of the chart which was then distributed to members of the subcommittee and others for criticism and revision.

The sharp differences of opinion that emerged

[1] Dunbar, Carl O., *et al.* (1942) *Correlation charts prepared by The Committee on Stratigraphy of the National Research Council*, Geol. Soc. Am., Bull., vol. 53, p. 429–434.

with respect to many of the correlations were at once discouraging and challenging. They indicated that the task of compiling such a chart would be difficult, but also showed how great was the need for synthesis of what was known and recognition of the problems that required further study. A determined effort was made therefore to secure discussion of controversial issues and critical evaluation of seemingly conflicting data so that the chart would represent not a mere collection of individual opinions but the considered judgment of a group of competent specialists. This effort has long delayed completion of the chart and has failed to achieve full agreement on some major problems and on many details.

It is not surprising that complete agreement is not yet possible. This system is thick and complex and is exposed in many and widely separated areas of outcrop. Throughout the Appalachian trough, where it is exceptionally well developed and where many of the uncertainties lie, facies changes of major importance are associated with folding and thrust faulting that commonly prevent simple or easy demonstration of the relations. Failure of an earlier generation to appreciate the importance of facies changes compounded the confusion by fixing interpretations that have been difficult to uproot. Field work by members of this committee, and others, during the last two decades has developed a growing appreciation of the importance of facies changes, but there is still much field work to be done.

For the most part the Ordovician rocks are richly fossiliferous, and their faunas have been the subject of many researches. It may seem surprising, therefore, that the faunas of parts of the system are still very incompletely known and inadequately described. G. Arthur Cooper's monographic study of the brachiopods of the Chazyan and Black River stages, now nearing completion, has already made possible many advances and will lay a firmer foundation than we have had for correlation in these strata, but there is still much paleontological work to be done.

It has been the purpose of the committee to summarize what is known but not to "establish" by majority vote or arbitrary decision correlations that are still insecure. Some of the larger problems are briefly discussed here, and many details are covered by the annotations. There has been no effort or desire to suppress minority opinions on matters of correlation, and the annotations in a good many places contain contradictory or alternative interpretations which should be a warning to the user that further study is needed.

Acknowledgments

During the years of this study the committee has received help from many others currently working in the Ordovician rocks who have published new data or who have criticized parts of the chart or have discussed problems of classification and correlation with members of the committee. Among those who deserve special thanks are Virgil Barnes for help on the Lower Ordovician of Texas and Oklahoma; W. E. Ham for data on the Lower Ordovician beds in Oklahoma; Philip B. King for his discussions of the sections in West Texas; E. I. Leith for help on the faunas of the Lake Winnipeg region and western Newfoundland; A. K. Miller for information on the Bighorn problem and on the nautiloid faunas of the Lower Ordovician; Ralph L. Miller and Chilton E. Prouty for data on the stratigraphy in the Appalachian Valley in Virginia; Reuben J. Ross for data on the trilobite faunas of the Lower Ordovician Series; and L. J. Weeks for help on the sections in Newfoundland. To Dr. C. J. Stubblefield we are indebted for information as to the date at which the Ordovician System was officially recognized by the Geological Survey of Great Britain.

The National Research Council gave financial support that permitted an all-day conference by the committee on January 25, 1948. This meeting was attended by R. S. Bassler, Josiah Bridge, Preston E. Cloud, Jr., G. Arthur Cooper, Byron N. Cooper, Carl O. Dunbar, Marshall Kay, A. L. Loeblich, and W. H. Twenhofel. G. Arthur Cooper again played host to the committee for conference in his office on November 18, 1950.

During the course of this work the committee has lost three members by death—Charles Butts, August Foerste, and Josiah Bridge. Although they did not live to see and approve the final result, each contributed in important ways to the chart.

Plan of the Chart

The chart attempts to cover the whole of the North American continent with one or more columns for each important area of outcrop. These are numbered consecutively at the top to facilitate cross reference. Vertical shading indicates a hiatus, and oblique shading lack of exposure. Broken formational boundaries accompanied by question marks indicate that the position of the boundary is uncertain.

The generalized section at each end of the chart serves as the standard against which correlations are made; contemporaneous deposits are placed at a common level in the chart. The vertical space alloted to the box representing each formation indicates its relative time span and may have little relation to thickness. A panel near the left end shows the presently understood ranges of some of the many important guide fossils on which the correlation largely rests. It has not been feasible to group these into a simple sequence of faunal zones as in some of the other charts in this series. It could have been done with some success for the Lower Ordovician, but in the Middle and Upper Ordovician rocks the faunal relations appear now to be too complex to be thus represented. At various horizons there are two or more faunal provinces, so distinct that the zones established in one would hardly be applicable in another. The graptolite shales carry a faunal facies having little in common with that of the limestones. Furthermore many of the common and useful genera have rather long ranges that overlap to such a degree as to imply lack of major hiatuses within the chief basins of accumulation. Many limited faunal zones can actually be recognized, but they are based upon species or groups of species rather than genera, and they are provincial in extent. They could not be represented simply on a chart for the whole continent, but it should be understood that they have played an important role in the correlations, nonetheless. In view of all considerations it was decided that the objective basis for correlation could be presented more fully and accurately by showing the range of genera as done here than by trying to establish faunal zones.

Unfortunately, the ranges indicated cannot in all cases be directly and unequivocally determined. No graptolite faunas, for example, occur in the same province with the type Chazyan, and the range of graptolites in that stage must therefore be determined from other regions where elements of both facies are involved. The complexity of this problem is suggested in the discussion of the range of the *Phyllograptus-Tetragraptus* faunas. The Bighorn problem is another illustration of the difficulty of establishing the ranges of some of the zone fossils.

The attempt to give proper credit to each member of the committee for his responsibility by placing the names of the compilers at the top of the columns leaves much to be desired. Specialization by Ordovician stratigraphers has been zonal rather than regional, and thus Bridge and Cloud have been much concerned with the Lower Ordovician correlations all across the chart and not with the rest, while B. Cooper, G. A. Cooper, and Kay have been much more concerned with the Middle Ordovician. Furthermore in some areas the columns represent a compilation of the work of others, and in some it involves much original work by the compiler.

Annotations

Annotations are arranged alphabetically by formations but do not cover all the units shown on the chart. Their purpose is to cite evidence for correlation differing from that indicated in the *Stratigraphic Lexicon*[2] or for evidence on formations not included therein, and particularly to express qualifications or alternative interpretations. In view of the fact that many of these comments express individual views to which other members of the committee might or might not ascribe, the author of each annotation is indicated by placing his initials in brackets at the end of his comments. Since the purpose is to provide for expressions of differences of opinion on controversial matters, no apology is needed if the annotations for some of the formations are completely contradictory.

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[2] Wilmarth, M. Grace (1938) *Lexicon of Geologic Names of the United States*, U. S. Geol. Survey, Bull. 896.

Bibliography

The bibliography makes no pretense of covering all the literature on this system, but it does include papers actually used in preparation of this chart. Numbers in the box at the bottom of each column indicate the items in the bibliography that refer particularly to that column.

Founding of the Ordovician System

The Ordovician System was born out of controversy and is the last of the widely accepted systems to gain recognition. By 1830 the stratigraphic succession had been worked out in England down to the base of the "Old Red" sandstone; but the older rocks, which underlie most of Wales and, as we now know, had been through the Caledonian disturbance, had received little attention and were still grouped together as the "Old Grauwacke."

In 1831 Sedgwick and Murchison resolved jointly to tackle this complex. Probably assuming that in general the sequence descended toward the west as it did in the higher strata, they divided the field, Murchison beginning his study near the Welsh border and working downward from the base of the Old Red, while Sedgwick went to the base of it in the Harlech Dome in northwest Wales and worked upward. After 5 field seasons each had worked out a thick sequence of formations which he regarded as a natural geologic system, and in August of 1835 they appeared jointly before the British Association for the Advancement of Science in Dublin, at which time Murchison proposed the Silurian System and Sedgwick the Cambrian.

No duplication was then suspected, but as work progressed and Murchison, in 1839, published his monumental *Silurian System*, it became evident that much of his Lower Silurian (Llandeilo and Caradoc) was also claimed by Sedgwick as part of the Cambrian. Thus a controversy began that soon reached epic proportions and for more than half a century divided the British geologists into two camps. No attempt can be made here to review the long and involved struggle to determine the position of the Cambrian-Silurian boundary, but the following facts deserve emphasis.

In defense of his claims, Sedgwick showed (1852) that the Caradoc of Murchison consisted of two parts separated in many places in the Welsh Borderland by an important unconformity. He proposed to restrict the name Caradoc to the lower part and introduced a new name, Llandovery, for the upper. He urged that this regional unconformity between the Caradoc and Llandovery was the natural boundary between Cambrian and Silurian systems.

Murchison was forced to recognize the break but took the view that since the older rocks were part of his original Silurian they must still be included. In his *Siluria* of 1854 he accepted this unconformity as the boundary between Upper Silurian and Lower Silurian but extended the latter downward to include all the rest of the Cambrian (which was submerged as a *group* in the Lower Silurian).

Although Sedgwick and his followers bitterly opposed this idea, Murchison became Director General of the British Geological Survey in the following year (1855), and Sedgwick's claims got little sympathy thereafter from that powerful organization. Probably the influence of Lyell did much to keep the Cambrian System alive for, although in his widely used textbooks he followed Murchison in treating the Cambrian as a group rather than a system, he never admitted it to be a part of the Silurian but drew the Cambrian-Silurian boundary between the Tremadoc and the Arenig beds of western Wales.

By the time of Murchison's death in 1871, Charles Lapworth was engaged in his epoch-making study of graptolite faunas of southern Scotland. This study, and his knowledge of other areas, convinced him of the existence of three distinct faunas in the Lower Paleozoic. Accordingly, in 1879, he proposed to restrict the Silurian System to the formations above the base of the Llandovery, the Cambrian to rocks below the base of the Arenig, and to recognize a third system for the strata between the base of the Arenig and the base of the Lower Llandovery, for which he proposed the name *Ordovician* (Watts, 1939). Unfortunately the contro-

versy between the followers of both Murchison and Sedgwick was still too highly charged with emotion for this to be readily acceptable to either faction. Although the new system found favor with many individuals—and in spite of the cogent arguments of Lapworth—the Geological Survey of Great Britain, out of deference to Murchison, continued to treat these beds as Lower Silurian until Geikie's retirement in 1900. Official publications seem not to record when and how Ordovician finally came to be adopted by the Geological Survey of Great Britain, but Dr. J. C. Stubblefield has kindly prepared for us the following memorandum which may be of historical interest.

"Geikie's last report in the Summary of Progress for 1900, published 1901, still uses the words 'Lower Silurian' on pp. 54–55, but Teall's first Summary of Progress, which was in 1901, published in 1902, uses 'Ordovician' without comment on pp. 17, 34, 37, and 61. Again in the Annual Report of the Geological Survey of the United Kingdom and Museum of Practical Geology, for the year 1901, published 1902, p. 7, one notices that 'Ordovician fossils' are referred to—again without comment that anything unusual was afoot. Concerning the usage of the word 'Ordovician' on maps, it seems that Index Sheet 11, dated 1902, still retained 'Lower Silurian'. The reason for this was probably that Index Sheet 3 which bore the colour tablets of this series of Index Maps (¼ inch/mile) had previously been issued and it would have been mistaken policy to change nomenclature for the concluding sheets of the series. The later ¼ inch/mile series started in 1907 and used 'Ordovician'.

"As far as I can find it seems that the first edition of the 25 miles/inch map of the British Isles published in 1906, was the first map issued by the Geological Survey to use the term 'Ordovician'. 1-inch Sheets 230 (Ammanford) and 253 (Mevagissey) both published in 1907, also use the word 'Ordovician'. The explanation for this time lag is not necessarily as mysterious as it might appear, since as far as I can ascertain, during the intervening period between 1902 and 1906 no maps were published on which rocks of this system were portrayed. So the outcome of all this seems to be that when Teall took over Directorship he appears to have been keen to use the word 'Ordovician' as occasion offered, but there were occasions when to use this word might have created confusion, i.e. Index Map aforementioned. It is unfortunate that he did not feel it necessary to leave a clear-cut statement of the policy which he was following as far as I can see. I have searched fairly thoroughly the likely places for such a published statement and I have consulted several other people, in both cases in vain, for something more positive."

Meanwhile the Ordovician had found favor among American geologists who were more detached from the controversy. It was soon espoused by Walcott, who as the leading student of the Cambrian in America had visited Wales in 1888 to study its type section. In 1894 Walcott became Director of the U. S. Geological Survey, and the Ordovician System was officially adopted by that organization in 1903 (24th Ann. Rept. by the Director, 1903, p. 21–27). In 1906 Chamberlin and Salisbury published volume II of their monumental *Geology* which immediately became the leading textbook for advanced students in this country, and in this work the Ordovician was accepted without qualification. Since then, with the exception noted below, it has been generally used by North American geologists.

A single departure from the use of the *name* Ordovician in America was that started by Clarke and Schuchert in 1903, in favor of the name Champlainian which had been used by James Hall in the Final Report of the Geological Survey of New York, Volume IV, in 1842 for approximately the same stratigraphical unit. It was adopted for some years thereafter by the Geological Survey of New York and was used by Schuchert in his *Historical Geology* in the editions of 1915 and 1924, but, although Champlainian clearly has priority over Ordovician by many years, its substitution at that late date seemed only to add to the long-drawn-out confusion, and it gained few adherents and is now no longer in use.

Boundaries of the Ordovician System

General discussion.—The Ordovician, like the Cambrian System, has its type area along the axis of the Welsh geosyncline. Both systems are thick there and almost entirely of clastic rocks. Rapid facies changes and contemporaneous volcanic activity introduced complexity that was compounded by tectonic disturbance at the close of the Ordovician and especially by the Caledonian disturbance at the end of Silurian time.

In spite of these difficulties, the stratigraphic and faunal succession is now well known, thanks to the patient labors of a long line of British

geologists, and the following sequence is now generally recognized in Northern Wales:

Silurian	Ludlow Series Wenlock Series Llandovery Series
Ordovician	Ashgill Series (Upper Bala) Caradoc Series (Lower Bala) Llandeilo Series Llanvirn Series Arenig Series
?	Tremadoc Series
Cambrian	Lingula Flags Menevian or Clogun shales Harlech beds

Lapworth proposed his new system to include all the beds from the base of the Arenig to the base of the Llandovery. These limits coincided with structural unconformities that were already widely recognized, but Lapworth emphasized rather the argument that if the early Paleozoic rocks were thus grouped into three systems each would be distinguished by general faunal characteristics as marked as those of other recognized systems. He even minimized the value of stratigraphic discordances which, he argued, might be impressive on a local scale without having general significance.

He concluded that the greatest faunal break in the whole early Paleozoic sequence was at the base of the Llandovery. Sedgwick and Murchison had both recognized the important structural discordance at this level, the former regarding it as the proper boundary between Cambrian and Silurian systems and the latter claiming it as the boundary between Lower Silurian and Upper Silurian. Indeed, both the faunal and physical breaks are so obvious that once the Ordovician System was recognized there has never been a dissenting opinion as to the location of its upper boundary at the base of the Llandovery in Wales.

The location of the Cambro-Ordovician boundary is not so obvious and has been the subject of some controversy. Although in most parts of the Welsh geosyncline there is no obvious discordance between Cambrian and Ordovician, there are places along the western flank of the Snowdon Range and in Lleyn Peninsula to the southwest of the Harlech Dome where the Arenig rests unconformably on the Tremadocian and oversteps westward onto various older formations, even to the Precambrian. This is the obvious and natural place to draw the Cambro-Ordovician boundary in this area, and this is the reason it was selected by Lapworth.

On the other hand, it may be noted that these relatively small areas of unconformity are very close to the western margin of the Welsh geosyncline and that the Cambrian deposits probably never extended much farther to the west.

In spite of this physical break, the Tremadocian faunas are in some respects more closely allied to the Ordovician than to the Cambrian, and, for this reason, equivalent strata in Scandinavia and in America are commonly classified as basal Ordovician. The most conspicuous faunal evidence lies in the graptolites which make a sudden appearance in the Welsh section at the base of the Tremadocian and range upward as important zone fossils in the Ordovician. Two such zones are recognized in the Tremadocian, a basal zone of *Dictyonema flabelliforme* being followed by a zone of *Clonograptus*. These also characterize the *Dictyonemaschiefer* of western Europe and the Schaghticoke shale of New York, and the Green Point shale of Newfoundland. Swedish geologists have long referred this horizon to the base of the Ordovician, and, although Ruedemann at first placed it at the top of the Cambrian (Ruedemann, 1903; 1904, p. 492–493), he also later came to regard it as basal Ordovician. This usage was adopted by the Geological Survey of New York in 1912 (Hartnagel, 1912, p. 32) and has since been generally followed by American geologists.

Thus it has come about during recent decades that, while British geologists drew the base of the Ordovician System at the *top* of the Tremadocian, most geologists on the Continent and in North America have drawn it at the *base* of the Tremadocian. Recently there has been a growing sentiment among the leading specialists in Great Britain to shift the boundary there to accord with the common usage in other parts of the world and with the faunal evidence, in spite of the obvious but

apparently more local physical break in the type area. See, for example, a discussion by Stubblefield, King, and Bulman of Poulsen's paper of 1946 (p. 335–337). Whittard (1952, p. 154–156) unequivocally places the Tremadocian in the Ordovician.

Age of the Richmondian Stage.—Although the top of the Ordovician System has never been in doubt in Europe, a controversial issue was introduced in America when Ulrich in 1911 (Revision of the Paleozoic Systems, Geol. Soc. Am., Bull., vol. 22, p. 339) proposed that the Richmondian strata should be shifted to the Silurian. He argued that the emergence of the continent after the great Trenton submergence had been more extensive than that between the Richmondian and the Medinan and that on this paleogeographic-diastrophic basis the Richmondian must go upward into the Silurian. His argument was immediately challenged by Schuchert and Cumings and others, and for a number of years the age of the Richmondian became a major controversy in American geology. For a time Ulrich's powerful influence developed a following so that Richmondian was classified as Silurian in a few of the State geological reports and appeared so in such important publications as Bassler's *Bibliographic Index of American Ordovician and Silurian Fossils* (U. S. Nat. Mus., Bull. 92, vols. 1 and 2, 1915). Gradually, however, the support for this idea waned, and the *coupe de grâce* was delivered by O. T. Jones in 1925 in a masterly analysis and comparison of the Ordovician and Silurian faunas of Britain and North America (Jour. Geol., vol. 33, 1925, p. 371–388).

Special Problems

Limits of the Chazyan Stage.—In its type area, the Champlain Valley, the Chazyan stage includes somewhat more than 1000 feet of relatively pure, thick-bedded limestone. These deposits are separated from the shale belt on the east by a major thrust zone (Logan's Line) and from contemporaneous deposits both north and south by a gap of more than 100 miles. Recognition of Chazyan rocks outside the Champlain Valley rests, therefore, entirely on faunal criteria. Unfortunately the Chazyan fauna has turned out to be a somewhat restricted and provincial facies not clearly recognizable elsewhere. Some elements of it appear down the Appalachian trough and even in the Arbuckle Mountains and the Cordilleran region, but generally these faunas are dominated by other genera and species. This is well illustrated by the Lincolnshire formation of Virginia and Tennessee which has been referred to the Chazyan by most students and is so placed in the present chart, but which G. A. Cooper believes should be lifted to the base of the Black River stage because of numerous faunal affinities with that stage that are unknown in the type Chazyan. The Table Head limestone of Newfoundland, likewise, is referred to the Chazyan because of its stratigraphic position and because of general faunal characteristics, but there are actually few specific identities in the Table Head and Chazyan faunas.

In the Champlain Valley the middle Chazyan, Crown Point, limestone is characterized by the very large gastropod *Maclurites magnus*, which occurs in abundance. In this region there is no similar species above or below, and thus, from the early days of Ordovician stratigraphy, *Maclurites magnus* came to be regarded as a guide to Middle Chazyan. It is now known, however, that similar large species of *Maclurites* occur higher in the Ordovician in the central and southern Appalachians.

Maclurites is not the only fossil that delayed understanding of the Chazyan. *Tetradium cellulosum* and *Cryptophragmus* are the two that led Ulrich and others to identify the Lowville formation in the Appalachians and in the Central Basin of Tennessee. In the southern Appalachians *Cryptophragmus* is common in the Witten formation, which was hitherto called Lowville. On the basis of its supposed Lowville age all rocks below were placed in the Chazyan. This accounted for the Chazyan age of the Ottosee and the Athens of Virginia. The latter formations with *Nemagraptus* and other important graptolites of the Normanskill assemblage were thus dated as Chazyan. In similar fashion the Carters formation of the Central Basin of Tennessee was dated as Lowville because of abundant *Tetradium cellulosum* in its lower beds. By this correlation the entire Stones River group was assigned to the Chazyan

in spite of the fact that the Stones River contained no Chazyan species other than *Maclurites*. It is now known that *Cryptophragmus* and *T. cellulosum* have a considerable range. The fauna of the Witten limestone accompanying *Crytophragmus* is that of the Chaumont or Rockland beds, and the Carters limestone of Tennessee is now recognized as equivalent to the Tyrone limestone and is correlated with the Rockland formation. The result has been to leave the scope of the Chazyan stage outside the Champlain Valley in confusion and uncertainty. The experience of this committee in trying to resolve this confusion suggests that it may be desirable to abandon Chazyan as a stage in the standard section and choose a new term with a new type section somewhere in the central or southern part of the Appalachian trough—one that would be useful in a standard section for the Ordovician of North America.

Black River Stage vs. Bolarian Series.—The fine exposures of Middle Ordovician strata along Black River Valley, west of the Adirondacks, was made known by the original survey of New York State (1836–1842) and has since been commonly regarded as a standard section for this part of the column in North America, the lower part constituting the Black River stage and the upper part the Trenton stage. These subdivisions are so used in the accompanying correlation chart.

Kay, on the contrary, has recently proposed to reject the Black River as a major unit in our standard section and to replace it by his Bolarian series, based upon a section in the Bolar Valley of Virginia. He would thus recognize in the Middle Ordovician not one series (Champlainian) but three—Chazyan, Bolarian, and Trentonian. Whether these three major subdivisions of the Middle Ordovician deserve the rank of stages or series is largely a subjective matter on which there may be wide difference of opinion.

However, the choice of a new name for the middle unit involves principles of stratigraphic nomenclature of far-reaching importance. In a recent paper Kay (1948, p. 1401) advances two arguments for this change. The first is that "the term Black River does not lend itself to conversion to a series name (Black Riverian), for it is not mononomical, nor do the two words blend euphoniously". The second is that the section in the Black River Valley is incomplete at the base, leaving a considerable hiatus between these beds and the Chazyan that is represented by sedimentary deposits in the central and southern part of the Appalachian trough (Ward Cove and Peery limestones of southern Virginia, and lower Shippensburg and lower Edinburg limestones of northern Virginia and southern Pennsylvania). A third reason for the change (personal communication) is that part of the section in Black River Valley is not nearly so fossiliferous as equivalent strata in the central and southern part of the Appalachian trough.

All three arguments involve principles that might be widely applied in stratigraphy, if they were accepted, but would result in great confusion.

It would be fortunate if all time-stratigraphic names in geologic literature were short, mononomical and euphonious, and could readily end in "ian"; but unhappily there are a host of venerable names deeply entrenched in the literature, as is Black River Stage, that would not qualify under such a criterion. To uproot and reject them would cause great inconvenience and confusion, and an effort to do so is not likely to be accepted by most stratigraphers. In the King's English we accept nouns as adjectives in such common terms as *hat rack*, *dog sledge*, *horse collar*, and *street car*—must stratigraphers make a fetish of the ending "ian"?

The second argument seems to have a more valid basis; yet this, too, has its drawbacks. If all stages and series had been established in a single unbroken sequence, no difficulty would arise; but, in reality, stages, like series and systems, have commonly been distinguished precisely because they were groups of strata bounded by hiatuses, and in every instance where a natural break—a hiatus—occurs between two stages, or series or systems, we have to expect that in other places, especially in the deeper parts of the geosyncline, strata will be found to fill or partly fill that gap. In such a case are we to abandon each stage or series or system as soon as additional strata are discovered elsewhere that are not represented in its type section? Or shall we merely extend it to include additional beds? The first alternative would lead to almost endless change and

much confusion. To reject a well-established stage or series in favor of another that embraces somewhat more fossiliferous beds presents similar drawbacks.

On the other hand, there is nothing sacrosanct about these larger categories of stratigraphic units. They must be modified to keep abreast of our understanding. Any section that does not actually serve as a standard for comparison and correlation cannot usefully be retained as part of the standard section. As discussed above, the present classification of the Middle Ordovician strata in North America has shortcomings. Particular difficulty is encountered in trying to recognize Chazyan equivalents outside the type area, and in locating the Chazyan-Black River boundary. Some modification of the present scheme seems to be indicated, but, in the absence of a comprehensive and satisfactory regrouping, the majority of the committee has favored retaining the traditional three stages—Chazyan, Black River, and Trentonian—for the present chart.

Upward range of the Deepkill facies.—The Deepkill shale, with *Tetragraptus* and *Phyllograptus*, has long served as a standard section for the shaly graptoliferous facies of the Lower Ordovician, and these genera were believed not to range higher. The Normanskill shale likewise was considered to be Chazyan, especially in its lower half which carries the graptolites *Nemagraptus*, *Dicranograptus*, and *Dicellograptus*. The Deepkill fauna has actually been found in association with Lower Ordovician faunas of the calcareous facies in numerous regions, and its age is well established. On the contrary, the Normanskill shale was referred to the Chazyan by Ulrich and Ruedemann because its *Nemagraptus-Dicranograptus* fauna is found also in the Athens shale in Virginia and eastern Tennessee where it intertongues with, or grades into, limestones that they regarded as Chazyan. Recent work by Cooper and Cooper (1946) has shown, however, that these limestones are of Black River age, and, if so, the Athens shale must also be post-Chazyan.

Meanwhile Dunbar and Leith found a *Phyllograptus-Tetragraptus* fauna in western Newfoundland at the top of the Table Head limestone which is correlated with the Chazyan. This graptolite fauna was discovered by Dunbar in 1918, and its field relations were carefully studied by Dunbar and Leith in 1933 when large collections of the graptolites were secured. This fauna is being described elsewhere, but its implications are so important that it could not be ignored in this chart. For this reason a brief summary of the circumstances is here presented.

The Table Head limestone is richly fossiliferous and is extensively exposed along the west coast of Newfoundland. It ranges in thickness from about 800 feet in Port-au-Port Bay area to nearly 1400 feet at Table Head. The lower part is light-gray, nearly pure, massive limestone, but the upper part is well bedded, more or less argillaceous, and darker, and at the top it grades over into black shale. In the Port-au-Port area the massive limestone is a little over 700 feet thick and is succeeded by about 35 feet of thin-bedded dark limestone and interbedded shale that forms a perfect gradation upward into the black graptoliferous shale (Schuchert and Dunbar, 1934, p. 67, Pl. 7A). The lower 35 feet of this shale member, from which the graptolites were secured, lies undisturbed and in perfect conformity with the limestones, but the succeeding part is soft and weak and has been crumpled so that its full thickness could not be determined. At Table Head the shale is about 300 feet thick. From the undisturbed lower 35 feet of this shale at Black Cove, about 1½ miles northeast of The Gravels at Port-au-Port, Dunbar and Leith collected a graptolite fauna including *Tetragraptus*, *Phyllograptus*, *Didymograptus*, *Cardiograptus*, *Cryptograptus*, *Isograptus*, *Diplograptus*, *Glossograptus*, and *Climacograptus*.

In the field, careful consideration was given to the possibility of overthrust of this shale from a lower position in the section onto the Table Head limestone, but for a number of reasons that idea had to be rejected. The transition from the limestone to shale is too gradual and too perfect; the stratification is too clear, and the graptoliferous shales too free of crumpling; the shale with its distinctive graptolite fauna occurs at the top of the limestone in other localities several miles apart; and finally when the graptolites were identified they revealed an association of Lower and Middle Ordovician genera that cannot be matched elsewhere in pre-Chazyan strata.

If the Table Head limestone is correctly dated, therefore, this is a Chazyan graptolite fauna.

So long as the Normanskill shale was believed to represent the Chazyan, the Table Head graptolites seemed anomalous. However, since the *Nemagraptus-Dicellograptus* fauna of the lower Normanskill is now assigned to the Black River Stage, as explained in the preceding section, there appears to be no reason to doubt the Chazyan age of the Table Head fauna. It may be the first truly Chazyan graptolite fauna thus far discovered in America. The association of genera found in this shale, however, is closely paralleled by that in the Llanvirn shale of Wales which Whittington correlates with the Chazyan.

The case for the Chazyan age of the limestone cannot be adequately presented here. We have seriously considered the possibility that it is older than Chazyan and, although younger than the Beekmantown, still belongs in the Lower Ordovician rather than the Middle, but, for numerous reasons, that idea also has been rejected.

In this region, for example, the Lower Ordovician is represented by the St. George dolomite, some 2000 feet thick, with a succession of faunas indicating a fairly complete representation of this series. The Table Head limestone is distinctly younger, resting with obvious erosional disconformity on the St. George formation, and being entirely nondolomitic, while the faunal break at the boundary is abrupt and complete.

The fauna of the Table Head limestone is large and diversified, including abundant gastropods, nautiloids, trilobites, and brachiopods along with representatives of several minor groups. Although it has been recognized as a Chazyan equivalent by Billings, Raymond, and others, it has a distinct provincial character with many genera not known in the type region of the Chazyan. Only the trilobites have been adequately described, and in a summary of these Raymond (1925, p. 178, 179) makes the following observations:

"In a broad general way, there are great similarities between the faunas of the Lenoir, Holston, and Athens on the one hand, and of divisions I, K, L, M, and N [i.e., the Table Head formation of Newfoundland] on the other. The Lenoir and Holston are limestones as are I, K, L, and M, whereas the Athens is composed of thin bedded limestone and shale, a condition somewhat paralleled in N. In the limestones of both regions we find such genera as *Illaenus*, *Pliomerops*, and *Sphaerexochus*, accompanied by other genera suggesting the normal Chazyan fauna, followed in each case by an influx of the so-called European genera."

The cephalopods show a stage of evolution much more akin to the Middle than to Lower Ordovician, even though not closely like those in the Chazyan. For example, the piloceratids, so characteristic of the upper part of the Canadian Series and so well represented in the underlying St. George beds of Newfoundland, are absent from the Table Head limestone. On the other hand one of the most common and striking forms in the middle part of the Table Head formation is a large actinoceratid, *Cyrtonybyoceras clouei*, fully as specialized as *Actinoceras tenuifilun* of the Black River Stage and quite unlike anything known in the Lower Ordovician. Perhaps one of the most significant ties is the brachiopod genus *Aporthophyla* which G. A. Cooper (personal communication) has found in the upper part of the "Pogonip" formation in the Roberts Mountains in Nevada (Column 64) in associations which he believes are Chazyan in age.

Although the evidence available rather definitely favors a Chazyan age for the Table Head formation, it must be admitted that the case is not closed and will not be until the Table Head faunas are fully described and analyzed.

Extent and importance of hiatuses.—A comparison of the many columns collated by Kay with those prepared by Cooper and Cooper reveals one striking difference—in the former many hiatuses break the sections and in the latter deposition is inferred to have been almost continuous with the exception of one major break at the top of the Lower Ordovician. To a considerable extent this is due to the fact that Kay's work has been mostly around the flanks of the Adirondack Dome and along the Adirondack Axis where subsidence was slighter and submergence was less continuous than in the deeper part of the Appalachian trough where Cooper and Cooper have worked. On the other hand it probably also indicates a difference in philosophical approach which is common among stratigraphers—a difference largely stemming from differences in field experience. About the flanks of the

Adirondacks, the thinning and disappearance of many units in the Middle Ordovician part of the section can be demonstrated as Kay has so clearly done in several papers. Work in such an area leads one to expect, and to look for, hiatuses. Farther from such positive areas the breaks are probably smaller, less frequent, and more difficult to detect. The absence of an expected faunal zone may then be the only evidence of hiatus, and even that may be due to facies differences rather than emergence. It must be noted, however, that Kay believes there are marked hiatuses in the Appalachian sections which Cooper and Cooper consider to have had continuous deposition. This will be indicated by comparison of columns 22 and 28 of the chart.

Facies changes.—It has long been recognized that the Ordovician System is represented by a detrital facies along the eastern margin of the Appalachian trough. Ulrich's notion that the shales and standstones were laid down in one or more separate troughs paralleling the sea in which the limestones were formed strongly influenced much of the work in this region until after 1920.[3] This idea is now discredited, and it is well known that in general the limestones change facies and grade over into detritals toward the eastern margin of the trough. Ruedemann was among the first to demonstrate this phenomenon when he proved that part of the Trenton limestone grades eastward into the Canajoharie shale,[4] and Kay (1937; 1943) has shown this kind of lateral change of facies to be common in the Adirondack region.

Relations in the central and southern Appalachians are suggested by Figures 1 and 2. The general change from calcareous rocks in the west to clastic in the east is made more complex not only by deep intertonguing of limestone and shale, but also by gradation of one type of limestone into another. Some of these lateral changes of facies are great and relatively abrupt. One of the most confusing factors has been the development of large lenticular masses of coarsely granular and commonly pinkish limestone (Holston facies) at a number of horizons. Another has been the similar development of the peculiar Mosheim lithology. If the structure were simple the true relations could be demonstrated conclusively by detailed field work; but in a region of structural complexity the larger pattern has been cut by thrust faults into isolated segments like the pieces of a jigsaw puzzle. Figures 1 and 2 are independent attempts to fit together essentially the same lot of pieces in the region about Knoxville, Tennessee. They illustrate at once the complexity of the problem and the kind of differences in interpretation that persist even among the best-qualified modern workers.

The Bighorn problem.—One of the most troublesome problems to be faced in constructing the chart has been the age of the Bighorn formation and its correlatives. Such formations are widespread in the Rocky Mountain region and form extensive outcrops in Manitoba and along the west side of Hudson Bay and farther north in the Arctic Islands, notably in Baffinland and Greenland. They are believed to record a very extensive arctic invasion of relatively short duration. They carry a large and diversified fauna that permits ready correlation from one area to another in this province, but has little in common with any of the faunas in the standard section based on the Appalachian province. Furthermore, these western and arctic faunas have a strange mixture of Mohawkian and Richmondian genera as a result of which there has been a good deal of uncertainty as to whether they were of Middle or Upper Ordovician age or whether in many areas Richmondian rested disconformably on Black River or early Trenton beds.

Contrasting views are briefly summarized by Twenhofel and Kay in the annotations on the Red River formation. Until a comprehensive and definitive study of the problem is made these divergent views cannot be reconciled. In representing these formations as Richmondian on the chart the committee has followed what appears to be the most widely favored view, but the reader should understand

[3] Ulrich, E. O., and Schuchert, C. (1902) *Paleozoic seas and barriers in eastern North America*, N. Y. State Mus., Bull. 52, p. 633–663; Ulrich, E. O. (1911) *Revision of the Paleozoic systems*, Geol. Soc. Am., Bull., vol. 22, p. 281–680, especially p. 512–13; Ruedemann, R. (1929) *Alternating oscillatory movements in the Chazy and Levis troughs of the Appalachian geosyncline*, Geol. Soc. Am., Bull., vol. 40, p. 409–416; Ruedemann, R. (1930) *Geology of the Capitol District*, N. Y. State Mus., Bull. 285.

[4] Ruedemann, R. (1901) *Hudson River beds near Albany and their taxonomic equivalents*, N. Y. State Mus., Bull. 42, p. 489–587.

that this is not the only view. Edwin Kirk has suggested (1930, p. 465) that these western faunas, showing affinities as they do with both Trenton and Richmond faunas yet not agreeing

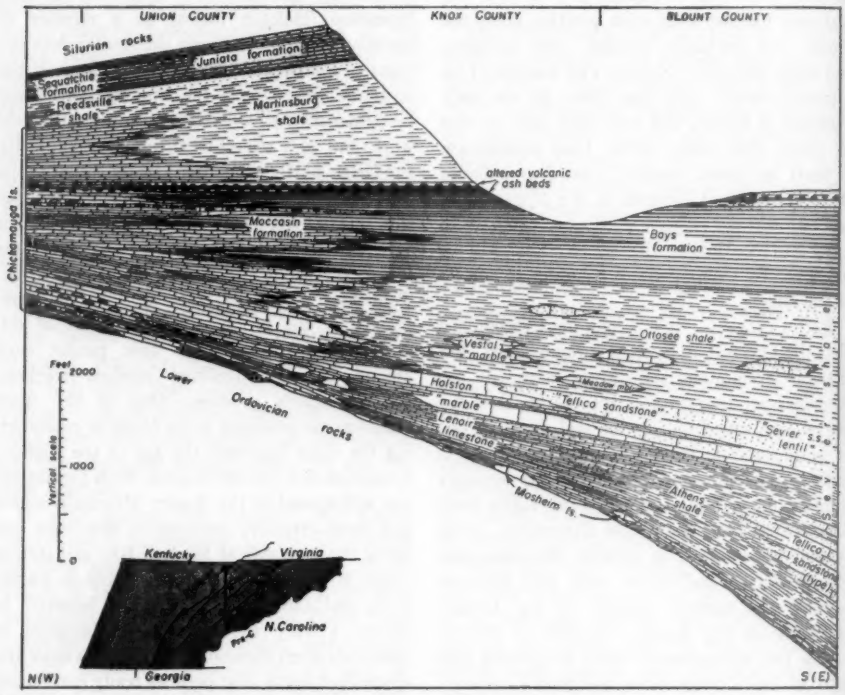

FIGURE 1.—DIAGRAM BY JOHN RODGERS INTERPRETING THE FACIES RELATIONS IN THE ORDOVICIAN ROCKS OF THE KNOXVILLE REGION, EASTERN TENNESSEE
The line of section is indicated by the line n-s in the inset map.

fully with either, may be the time equivalent of the Maysvillian but in a different province and a different facies.

A very comprehensive study of the problem by A. K. Miller is awaiting publication as a special paper of The Geological Society of America.

CORRELATION OF THE ORDOVICIAN SYSTEM OF GREAT BRITAIN WITH THAT OF NORTH AMERICA

By Harry B. Whittington

The type areas of the various series of the Ordovician System in Great Britain are in North and South Wales, the Welsh Borderland, and northern England. The sediments are predominantly graywackes, sandstones, and shales, with some limestones, and interbedded volcanic ashes. In some of the areas the strata are folded and cleaved. Shelly faunas (brachiopods and trilobites) are commonest in these rocks, but graptolites occur (generally in dark shales) in interbedded, or sometimes the same, strata. In 1879–1880 Charles Lapworth suggested 9 graptolite zones in the Ordovician. Subsequently a more-detailed division into 15 zones (Elles and Wood, 1914) was proposed, and Elles (1925) has discussed the zonal assemblages. The early establishment of these zones, and the occurrence of graptolites in most British Ordovician rocks, led to the almost exclusive use of graptolites for dating and correlation. Only in the last 25 years have intensive studies of the shelly faunas been undertaken, and we are still far from any

complete zonal scheme in Britain based on these faunas.

In the Ordovician of western Europe shelly faunas are strikingly different in different provinces (although these provinces may have considerable extent), but the characteristic graptolite assemblages may be recognized in these different provinces. Thus graptolites have enabled correlation between Britain and Scandinavia, though the shelly faunas of, for example, the lower Ordovician of Sweden are almost entirely different from the British fossils of the same age. Thus, in attempting correlation between Britain and North America, it seems that graptolite faunas offer the most promising line of approach, for there is often little in common (with certain exceptions) between the shelly faunas. Certain difficulties at once arise in making this attempt. The type areas of the various North American series are dominantly in calcareous rocks of simple structure. The fossils are of the shelly faunas, and such graptolites as occur have been little studied. The shaly sequences of British Columbia, Quebec, and New York State, which yield abundant graptolites, are in areas of complex structure, and correlation with the standard series is unsatisfactorily vague. The difficulties inherent in having a calcareous facies, apparently devoid of graptolites, as a standard is illustrated by the Chazy correlation problem in North America. More intensive study of graptolites, and especially those that occur in dominantly calcareous sections, would certainly contribute to solutions of intra- and extra-North American correlation problems.

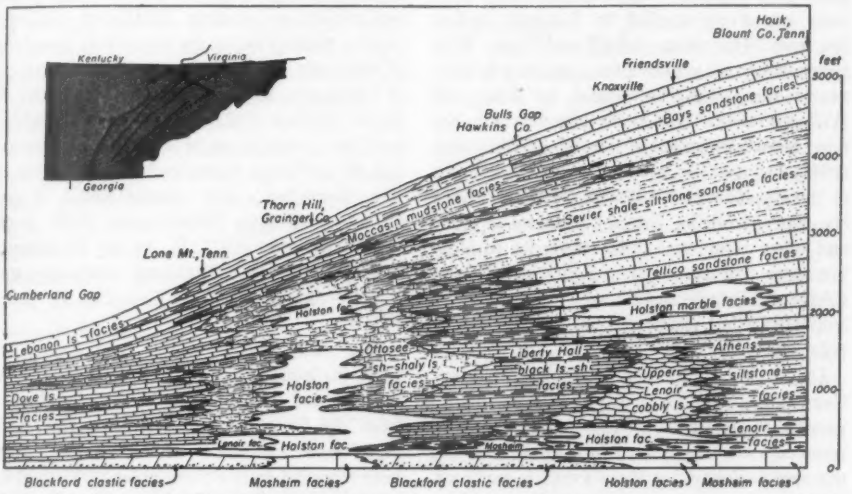

FIGURE 2.—DIAGRAM BY BYRON COOPER INTERPRETING THE FACIES RELATIONS IN THE ORDOVICIAN ROCKS OF THE KNOXVILLE REGION, EASTERN TENNESSEE

The line of section is indicated in the inset map. Note that it is in two parts separated by a considerable offset along the strike.

The founding of the Ordovician System and development of the standard series have been discussed by Dunbar. The graptolite zones generally recognized are:

Ashgill	*Dicellograptus anceps* *Dicellograptus complanatus*
Caradoc	*Pleurograptus linearis* *Dicranograptus clingani* *Climacograptus wilsoni* *Climacograptus pellifer* *Nemagraptus gracilis*
Llandeilo	*Glyptograptus teretiusculus*
Llanvirn	*Didymograptus murchisoni* *Didymograptus bifidus*
Arenig	*Didymograptus hirundo* *Didymograptus extensus* *Dichograptus*
Tremadoc	*Bryograptus* *Dictyonema*

In the present paper the series names "Caradoc" and "Ashgill" are used rather than "Lower Bala" and Upper Bala" respectively. The first two are not synonymous with the latter pair, and the Caradoc shelly faunas have been intensively studied by Bancroft, and a few graptolites occur. Ashgill and Upper Bala are probably not synonymous, particularly if we accept the Ashgill as defined by King and Williams (1948). This latter reference is to the most recent discussion of the Ashgill. Whittard (1952) has recently given a summary account of the Caradoc, and Williams (1953) described the type Llandeilo. General accounts of these and other type areas, and references to older literature, are contained in Smith and George (1948) and Pringle and George (1948). Stubblefield (1939) has considered the distribution of trilobites in the Ordovician.

Dr. O. M. B. Bulman, Sedgwick Museum, Cambridge, and Dr. Alwyn Williams, University of Glasgow, kindly offered critical comments on the views expressed herein, but the responsibility for these views is my own.

Tremadoc

At least part of the Tremadoc Series is represented by the *Dictyonema* shale of Quebec, the Schaghticoke shale of New York, and the Green Point shale of Newfoundland (Bulman, 1950). Characteristic of the Upper Tremadoc *Ceratopyge* limestone of Norway and Sweden is the trilobite *Apatokephalus*, and this genus occurs in the Highgate limestone of Vermont, the lower Ordovician of the Canadian Rocky Mountains, and in the lower Pogonip of Nevada. The basal portions of the Ordovician Pogonip limestone and the Garden City limestone of Utah and Nevada yield *Nanorthis*, *Symphysurina*, and *Clelandia* (Ross, 1951; Hintze, 1953) and are probably to be regarded as of Tremadoc age. *Clelandia* occurs in the Tribes Hill limestone of New York and possibly in the Oneonta dolomite of the Upper Mississippi Valley. Wilson (1952) has recently expressed the view that the Gasconade and possibly Roubidoux stages are Tremadoc in age.

Arenig

The Levis, Deepkill, and Glenogle shales contain graptolite assemblages suggesting that they were deposited during the same period of time as the Arenig rocks (Elles, 1933; Rudemann, 1947). Apparently the only clue in limestone sequences in North America to possible Arenig or earliest Llanvirn age is the recognition by Decker (1941) of *Didymograptus protobifidus* in the Smithville limestone of Arkansas, the West Spring Creek formation of Oklahoma, and the Marathon limestone of Texas. Poulsen (1927) has recorded *D. bifidus* from the lowest layers of the Nunatami formation of northwest Greenland. Higher layers of this formation yield characteristic Upper Canadian trilobites (Whittington, 1953). Poulsen's illustration (1927, Pl. 19, fig. 2) suggests that perhaps the Nunatami *Didymograptus* is more akin to the late Canadian *D. protobifidus*.

The shelly faunas of the type Arenig are most inadequately known. Such trilobites as are recorded (Stubblefield, 1939) are unknown from the Canadian of North America, and, vice versa, Canadian trilobites have rarely been recorded from British areas (Whittington, 1953, p. 658, 662). It is indeed an approximation to suggest that the post-Gasconade portion of the Canadian spans Arenig time.

Llanvirn

The upper portions of the Levis, Deepkill, and Glenogle shales contain the *Didymograptus bifidus* assemblage, succeeded by beds with *Glyptograptus dentatus*, other diplograptids, and *Tetragraptus*, *Phyllograptus*, *Isograptus*, *Cryptograptus*, etc. (Rudemann, 1947). Bulman (1931, p. 13) expressed the opinion that these *G. dentatus* beds extend to the close of Llanvirn time, and thus apparently represent the *D. murchisoni* zone. The Table Head formation graptolites collected by Dunbar and Leith may be of approximately this age.

According to Ruedemann (1947) the Joins formation of Oklahoma and similar beds in Arkansas represent the *D. bifidus* zone. The brachiopods *Desmorthis* and *Anomalorthis* are present in the Joins, together with an undescribed species of *Pseudoolenoides* Hintze, 1953. This latter genus is characteristic of Zone M in Utah, from which (Swan Peak quartzite) Ross (1951) has also recorded *Anomalorthis* and *D. bifidus*. This widespread

lower Llanvirn assemblage is probably present farther west in Nevada.

Llandeilo

The graptolite assemblages that existed during the gap between late Deepkill and early Normanskill are not certainly known, though they may be represented in the higher Glenogle shale. Thus it is not possible at present to recognize a Llandeilo graptolite fauna in North America. If the lower Normanskill and Athens shale are regarded as belonging to the *Nemagraptus gracilis* zone, at least some of the rocks placed immediately below this level on the chart may be of Llandeilo age. The brachiopod *Rostricellula* occurs in such rocks and is present in the upper Llanvirn and Llandeilo of South Wales (Williams, 1953).

Chazyan Series

The implication of the correlation suggested here is that the strata included in the Chazyan series in the chart are approximately equivalent to the Llanvirn and Llandeilo Series of Britain. The positions of the *Didymograptus bifidus* and *Nemagraptus gracilis* zones in North America, as portrayed in the chart, afford the reasons for proposing this interpretation. The suggested boundary between Llanvirn and Llandeilo is a gross approximation, and, while some strata in a lower Chazyan position on the chart may be of Llanvirn age, it should not be assumed that all are; *e.g.*, the age of the New Market, Lenoir, and Tumbez limestones in British terms is unknown at present, as, indeed, is that of the type Chazy limestone.

The chart shows that a break occurs above Canadian strata in Vermont, New York, the Appalachian Mountain region, and the Central States. In some of these areas, as well as in Maritime Canada, Ontario, and the Cordilleran region, there is a break below strata of Mohawkian age. Such formations as the Levis and the Deepkill shales, the Pogonip limestone, and the Garden City limestone and Swan Peak quartzite do not apparently extend throughout Chazyan time, and from such successions as do appear to do so the faunas are not well known. It is therefore not surprising that intra-Chazyan and extra-North American Chazyan correlations are uncertain.

Caradoc

The Mount Merino member of the Normanskill shale and the Athens shale contain the *Nemagraptus gracilis* fauna and presumably were laid down in early Caradoc time. The vertical range of *N. gracilis* may be considerable, and the zone therefore thick. Further, there is a break at the base of beds containing *N. gracilis* in certain British areas, as there seems to be also in certain North American areas. Correlation within the zone is thus generalized. Support for this correlation is given by the shelly faunas, particularly trilobites, of the lower Edinburg formation (and correlatives), formerly thought to be of Chazyan age, which are remarkably like early Caradoc faunas of Southern Scotland and Ireland (Stubblefield, 1939, p. 58–60; Cooper, 1953). Many elements of the type Cardoc faunas, *e.g.*, the trinucleid genera used as zonal indices, have not been found in North America, but other elements—*e.g.*, the brachiopods *Resserella* and *Reuschella*—have recently been described from the Appalachian Mountain region (Cooper and Cooper, 1946).

The graptolites of the Austin Glen member of the Normanskill shale lack *N. gracilis* but include *Leptograptus*, *Dicellograptus*, *Climacograptus*, and *Cryptograptus* and are like those of the upper "Athens" of Northern Virginia (Cooper and Cooper, 1946, p. 61). A somewhat similar fauna has been recognized by Whittington (1952) from the lower Viola limestone, and possibly these faunas represent the *Climacograptus pellifer* and/or *C. wilsoni* zones. The Canajoharie shale with *Corynoides*, *Dicranograptus*, diplograptids, etc., may represent the *D. clingani* zone. *Pleurograptus linearis* is well known from the Holland Patent shale, and part or all of the succeeding Lorraine shale may belong in this zone. Thus Caradoc equivalents in North America appear to extend from lowest Mohawkian to highest Edenian or Maysvillian.

Ashgill

Dicellograptus complanatus and *D. anceps* were both recorded from the Polk Creek shale of Arkansas, and *D. complanatus* from the Sylvan shale (overlying the "Fernvale") of Oklahoma, by Decker (Ruedemann, 1947,

p. 91). Presumably these strata are of approximately Ashgill age. The Whitehead formation of Quebec (Cooper and Kindle, 1936) contains a striking number of European genera, including the trilobites *Tretaspis* and *Diacalymene*, characteristic of the Ashgill (King and Williams, 1948), and *Holotrachelus*, known from the Boda limestone (Ashgill) of central Sweden. "*Brachyaspis*" also occurs in the Whitehead formation, the Maquoketa shale, and the Upper Ordovician of Anticosti Island. Other elements in the Whitehead faunas are less suggestive of an Ashgill age.

Annotations

Alsate shale. The Alsate shale may represent the *Taffia* [=*Hesperonomia*] zone of the El Paso limestone, or it may have a somewhat lower position (Kirk, 1934). [W. H. T.]

P. B. King (1937, p. 32) found *Oncograptus* in this formation along with *Tetragraptus*, *Phyllograptus*, and *Didymograptus*. On this basis Ruedemann referred it to the highest zone of the Deepkill shale. [C. O. D.]

Athens formation. The Athens is probably the most misrepresented of all the Appalachian Ordovician formations. A general impression exists that the typical Athens is a black shale containing abundant graptolites, and, indeed, this is the type of rock to which the name Athens has been so widely applied in Virginia. As revealed in a well-exposed section along Hiwassee River near Calhoun, McMinn County, Tennessee, the Athens belt that passes through the type locality at near-by Athens is a cobbly, irregularly bedded calcareous siltstone. Although some graptolites do occur in the typical Athens, they are not abundant. The entire body of Athens strata along Hiwassee River, aggregating several hundred feet of shale and siltstone, comes within the range of the stratigraphically important brachiopod genus, *Christiania*, which occurs in the lowest and also in the highest beds. Northeastward, this formation interfingers with and grades into a body of cobbly limestone characteristically developed at Christiansburg and Friendsville, Tennessee, which has for a long time been considered part of the Lenoir. Recently Ulrich and Cooper (1938) referred to it as the "Upper Lenoir." The similarities between the "Upper Lenoir" and the true Lenoir are more apparent than real. It can be positively affirmed that the *Christiania*-bearing "Upper Lenoir," such as occurs at Friendsville, Tennessee, is not a part of the type Lenoir, because it succeeds a full development of the Lenoir in all essential respects the same as that in the vicinity of Lenoir City, Tennessee. Also, the faunas of the "Upper Lenoir" and of the Athens are unrepresented in the type Chazy limestone of New York.

For many years, the Athens formation has been regarded as Chazy, on the ground that it occurs well below a limestone identified as the Lowville limestone of New York. Ulrich (1911) and also Butts (1940) considered the Lowville limestone to constitute the lower Black River, and all the subjacent post-Canadian formations to be Chazyan. The identification of this Appalachian limestone formation as an unequivocal correlate of the New York Lowville has been shown (Cooper and Cooper, 1946, p. 60–62) to be erroneous. Thus the Athens, though still regarded as of Chazy age by many geologists, is not linked with the Chazy by fossils or by stratigraphic position. As discussed under the Lincolnshire and Murat limestone, the Athens and its equivalents overlie beds no older than very late Chazy and possibly even younger than any part of the type Chazyan. Thus the Athens is regarded as younger than Chazyan. [B. C.]

Athens shale. The Athens shale of the type belt is pre-Holston and grades laterally into the Lenoir and "Upper Lenoir" limestones of the Friendsville section. As *Christiania* occurs at the base south of Athens, it may range deeper there than at Friendsville. The Athens "shale" of the type area is chiefly shaly limestone, with interbedded cobbly silty limestone. [J. R.]

Auburn chert. The presence of *Rafinesquina aburnensis* Fenton in this formation suggests an early Trenton age. This fossil, with abundant *Pionodema*, indicates correlation with the Guttenberg division of the Decorah. The same argument holds for the shales above the Plattin in eastern Missouri which have been correlated with the Spechts Ferry division of the Decorah. These two contain abundant *Rafinesquina* and *Pionodema*. [G. A. C.]

The Auburn chert is placed in the lowest

Trentonian to conform to the placement of the Spechts Ferry shale with which it has been correlated. [M. K.]

Austin Glen member of Normanskill shale. The Austin Glen sandy graywacke and argillite is the upper member of the Normanskill shale of Ruedemann (1945). Though he places the Rysedorph above it, the latter stratigraphically overlies the Mount Merino shale, lower Normanskill. Kay believes the Austin Glen may be middle Trentonian, an eastern extension of the lithologically similar Schenectady formation. [M. K.]

Barrel Spring formation. The Barrel Spring formation (Phleger, 1933) is composed of limestones and shales which contain few fossils. Phleger states that the fossils indicate the age to be Trenton. Twenhofel considers this unlikely and thinks it may be of Richmond age. [W. H. T.]

G. A. Cooper thinks the Barrel Spring formation, like the Eureka quartzite, may extend down to include beds of Black River age. *See* Eureka Quartzite. [G. A. C.]

Bays formation. The Bays is a predominantly red sandy formation more or less confined to southeastern belts of the southern Appalachian Valley of Tennessee. It contains an intercalated zone of light-gray coarse-grained conglomeratic sandstone which in the Bays Mountain syncline was misidentified by some early workers as the Clinch sandstone (basal Silurian or Medinan). The buff shales of the Martinsburg formation (Trenton-Maysville) overlie the Clinch-like sandstone in the Bays formation. Butts (1940) maintained that the Bays sandstone was not present in Virginia; however, the red beds and included white quartzites which he, and earlier Woodward (1932) had identified as Moccasin in the Catawba-Pearis Mountain belt of Montgomery and Roanoke counties, Virginia, is precisely like the Bays formation of Tennessee. Its anomalous occurrence in the middle of the Appalachian Valley is the result of transposition of large segments of the Paleozoic rocks many miles northwestward from their original position. The Bays facies rather than the Moccasin mudrock facies prevails along the Walker Mountain belt from the western terminus of the mountain in Washington County, northeastward nearly to Chatham Hill, Smyth County, and occurs also in Crockett Cove, Wytho County, Virginia. Inasmuch as the Moccasin formation was previously linked with the Lowville, a Black River age has been rather generally accepted. As discussed under the Moccasin formation, the latter may be late Black River or early Trenton, and this implies that the Bays is also probably younger than the Lowville. [B. C.]

The red Bays formation is the coarser southeastern equivalent of the red Moccasin formation (including the Bowen of Cooper and Prouty, 1943). Probably it does not extend much below the top of the Wardell, and almost certainly it nowhere rests on "Tellico" of either usage (see under heading Tellico) or Athens equivalents in the Bays Mountain area. [J. R.]

Beaverfoot limestone. The Beaverfoot limestone was named by Burling (1922, p. 453) for beds in the Beaverfoot Range that he considered of Richmondian age. Walcott (1924, p. 13) listed fossils that Kirk had identified for him and recognized its age as Richmondian and equivalent to that of the Stony Mountain formation of Manitoba. Alice Wilson (1926) described the fauna and concluded that part, at least, of the Beaverfoot limestone was of Gamacian age. [C. O. D.]

Beldens limestone. The Beldens limestone was thought to be equivalent to the Valcour by Cady (1945), but Kay later considered it older than the base of the Chazyan of New York (Kay and Cady, 1947). The persistence of the Burchards and Beldens formations, the Chipman group, above the Bascom in the Middlebury synclinorium, their absence to the west where Bridport overlies the Bascom, and the presence of *Goniotelus* sp. in the Weybridge tongue in the Beldens, suggest that the Beldens limestone is an eastern offshore facies of the Upper Canadian Bridport dolomite. [M. K.]

Bighorn formation. See Red River.

The Bighorn formation is divisible into a basal sandstone member (Lander member), a middle massively bedded dolomite member, and an upper flaggy, thin-bedded dolomite unit (Leigh member). Miller (1930; 1932) has analyzed the faunas of the formation and, while recognizing faunal resemblances to the Trentonian, cites forms like *Rhynchotrema capax*, *Dinorthis subquadrata*, and *Platystrophia*

acutilirata as evidence of Richmondian age. [C. O. D.]

Billings formation (Central and Southwestern Ontario). In the vicinity of Lake Ontario, strata of Collingwood and Gloucester age consist of about 120 feet of black, grey, and brown, bituminous and calcareous shale, which lie upon the Cobourg (Trenton) and are in turn overlain by the soft blue and grey shales of the Blue Mountain formation. To the Gloucester strata, Caley (1940) applied the name Billings which was carried over from the Ottawa Valley. He defined the formation as lying "between the Trenton below and the Dundas formation above" (p. 13). He noted that "the thin series of alternating limestone and shale overlying the Trenton at Ottawa and called the Eastview formation [Collingwood age] is apparently absent in the present map-area" (p. 13); also, he did not consider the Blue Mountain formation to be present in the vicinity of Toronto. It is now known that the Billings formation (Caley), by definition, must comprise Collingwood, Gloucester and Blue Mountain strata and a greater span of time than the Billings formation (Wilson) in the Ottawa Valley. Because the terms Collingwood and Gloucester are now time terms in the Ontario Ordovician, clarification of the above situation by the introduction of rock unit terms, and the restriction of the term Billings to the Ottawa Valley is under consideration. [B. A. L.]

Blackford formation. Following the original usage as introduced by Butts (1940, p. 126–133), Cooper and Prouty (1943, p. 862–863) defined the Blackford formation as including at the top the blocky chert zone with *Dinorthis holdeni*. Subsequently Cooper (1948) redefined the Blackford, excluding the blocky chert zone and elevating the latter to formation status under the name Elway limestone. The age of the Blackford according to Butts (1940, p. 126, 133–134) was lower Stones River Murfreesboro, but, as Cooper (1945, p. 268–272) has shown, the Murfreesboro limestone equivalent in southwestern Virginia occurs hundreds of feet above the Blackford. Cooper and Cooper (1946, p. 51–53) have shown that the Blackford red beds contain intercalations of limestone with typical Chazy fossils which link it unmistakably with the typical Lenoir of Tennessee. The Blackford facies, though lithologically distinctive and everywhere occurring just above the top of the Knox group, probably is considerably younger on the northwest side of the Appalachian Valley—as, for example, in Powell Valley of Lee County, Virginia—than in the middle Appalachian belts where it is most typically developed. This conclusion is based on the discovery of Lincolnshire fossils in beds of Blackford lithology just above the Knox dolomite near Rose Hill School, Union County, Tennessee, which has not been previously reported. [B. C.]

Black River limestone. The Black River limestone or group comprised the Pamelia, Lowville, and Chaumont formations in New York and Ontario (Young, 1943). The Bolarian Series (Kay, 1947) is thought to include the Black River stage as represented in New York, plus certain older and younger beds in Virginia and West Virginia and Pennsylvania. [M. K.]

Bolarian Series. The Bolarian Series (Kay, 1947; 1948) comprises rocks younger than the Lincolnshire limestone, classed as upper Chazyan, and older than Nealmont limestone, classed as lower Trentonian. The Black River group is a lithologic unit included in the Bolarian Series, but representing only a part of Bolarian time. [M. K.]

Botetourt limestone member. The beds so referred to in the Appalachian columns constitute essentially the same unit which Butts consistently identified as the Whitesburg limestone. The change in terminology is necessitated by the fact that the Whitesburg, as originally defined (Ulrich, 1930), is an objective synonym of the prior name Liberty Hall limestone. The discovery of the Botetourt limestone at the bottom of the Chambersburg limestone and also at the bottom of the Liberty Hall limestone which was formerly identified as Athens is an important link in the correlation of the Liberty Hall or "Athens" black limestone and shale with the Chambersburg limestone of the Shenandoah Valley. [B. C.]

Bowen formation. Although of Moccasin facies, the Bowen formation was not included in the original description and definition of the Moccasin (Campbell, 1894; Cooper, 1944, pl. 9). The Bowen is separated from the Moccasin

by the Witten limestone, which Butts regards as an intercalation of Lowville limestone in the Moccasin formation. The Bowen occurs along the entire 165-mile length of Clinch Mountain and also in the next belt of outcrop to the northwest, which passes through Copper Creek, Virginia, and Evans Ferry, Tennessee. Mud cracks and ripple marks have been said to be very characteristic of the Moccasin formation of Virginia; most of the "Moccasin" mud cracks which have been illustrated (Butts, 1940; Cooper and Prouty, 1943; Cooper, 1944) are actually in the Bowen formation. [B. C.]

Bridport dolomite. The name Providence Island dolomite was proposed by Ulrich (Ulrich and Cooper, 1938) for the beds of Beekmantown "E" (Brainerd and Seely, 1890) in the northern Lake Champlain area. In the typical locality of the sequence in west-central Vermont, Cady (1945) designated the rocks of Beekmantown "E" as the Bridport dolomite. [M. K.]

Bromide formation. This formation contains a zone with large *Sowerbyites* at its base. This zone is suggestive of the Lincolnshire formation, of the Appalachians. Lower Bromide contains considerable green shale with *Sowerbyites* near the base but typical Black River types throughout. In places the *Sowerbyites* beds become reef limestones as exhibited in the road cut 1.8 miles south of Sulphur, Oklahoma.

Upper Bromide consists of light-colored limestone and abounds in small *Doleroides* and other fossils strongly suggestive of Ridley and Wardell. Although the Bromide has been dated as Trenton by Loeblich, this assignment is not corroborated by the brachiopods. [G. A. C.]

Browns Mountain group. The Browns Mountain group consists of the two formations, Baxter Brook above and the James River below (Williams, 1914). The lithology is one of shales and argillites, and fossils are known only from the James River formation. These consist of two species of atremate brachiopods which indicate assignment to the Canadian. [W. H. T.]

Burchards limestone. See Beldens limestone.

Cannon limestone. There is some question of the correlation of the Cannon limestone with beds elsewhere in Tennessee and Kentucky. It has been listed as equivalent to the Perryville[5] limestone of Kentucky. It has also been suggested that the Bigby limestone of Tennessee, which is absent on the eastern flank of the dome, is represented in a different faunal and lithological facies in the lower Cannon. In spite of Bassler's (1932) view that the Cannon overlaps the underlying formations over a wide area, Wilson (1932) showed that the Bigby and Cannon limestones are of the same age and the overlap is one of facies. He recognized three facies:

(1) Irregularly bedded coarse-grained, phosphatic limestone (Bigby facies), thickest along the western part of the central basin.

(2) Fine-grained, dense dove-colored limestone (Dove facies) which occurs as lentils that attain a composite maximum thickness along a north-south belt a short distance west of the axis of the Nashville Dome.

(3) Fine-to-medium-grained, blue-gray limestone (Cannon facies), thickest along the eastern part of the central basin. [A. C. McF. and E. R. C.]

Cape Calhoun formation. This formation, including about 750 feet of brown and gray limestone, carries a prolific fauna (Koch, 1929, p. 32–37) that is unquestionably part of the widespread assemblage represented in the Stony Mountain formation of Manitoba and the Bighorn dolomite.

In 1929 Koch tentatively separated the lower 30–40 meters of brown limestone as the Troedsson Cliff formation, suggesting that it might be of Trenton age, but it is characterized by *Receptaculites arcticus* which also occurs in the higher beds, and the Troedsson Cliff formation seems to have been abandoned in Koch's later work as it was in Teichert's work of 1939 (p. 111). [C. O. D.]

Cape Clay formation. The Cape Clay formation has yielded *Ophileta*, *Helicotoma*, *Clarkoceras*, *Histricurus*, and *Symphisurina* (Teichert, 1939, p. 110) and is placed low in the Canadian. Poulsen (1946, p. 307) correlates it with the Gasconade, Oneota, and Chepultepec formations. [C. O. D.]

Cape Weber limestone. From the Cape Weber

[5] As then understood the Perryville was uppermost Lexington. It has recently been correlated with the Benson limestone. This is in keeping with Wilson's findings in Tennessee.

limestone of Northeast Greenland Poulsen (1937, p. 68) recorded a fauna of late Canadian age with *Bolbocephalus*, *Petigurus*, etc. He recognized the Cape Weber fauna in collections made by Bentham on Bache Peninsula, central eastern Ellesmere Land, and from structural relations reported by Bentham he inferred (1946) that the Weber formation should overlie the Nunatami formation. However, Troelsen later (1950, p. 47–53) identified the Weber formation in Bache Peninsula and in Washington Land, Northwest Greenland, where he found it to underlie the Nunatami formation in the type area of the latter. [C. O. D.]

Cape Webster formation. This unit overlies the Nunatami formation and is disconformably overlain by the Gonioceras Bay limestone of Black River age. It must therefore be of latest Canadian or Chazyan age or both, but few fossils in it have been accurately identified. Poulsen (1937, p. 71) correlates the lower part, at least, with the highest Canadian. [C. O. D.]

Carman quartzite. See Youngman formation.

Carters limestone. Born and Burwell's (1932) report on Clay County, Tennessee, shows that the Carters formation, which is limited to the west side of the Nashville Dome, is in contact with the Trenton and no Tyrone is present. Two bentonite beds are recognized, the Mud Cave at the contact and the Pencil Cave about 10 feet below. At Nashville, Tennessee, the Tyrone, with a thickness of 11–15 feet, is separated from the Carters by a thin bed of bentonite (Bassler, 1932) that would correspond to the Pencil Cave layer. These two bentonites presumably correlate with the two conspicuous ones in Kentucky at the Tyrone-Lexington contact and 20–30 feet below the top of the Tyrone. This would indicate an overlapping facies relationship between the Carters and Tyrone. [A. C. McF. and E. R. C.]

Cassin formation. The Cassin formation, named by H. P. Cushing (1905) following a suggestion by R. P. Whitfield (1890), included the well-known fossiliferous layers at Fort Cassin, Vermont, plus overlying practically unfossiliferous layers to the top of the Beekmantown dolomite in the Champlain Valley. It included approximately the upper half of Unit D (D_3 and D_4) and Unit E of Brainerd and Seely. In mapping this area, Cady (1945) and others have found it more convenient to recognize Brainerd and Seely's original units than to use the Cassin formation, and Cady has used for those units the formation names given in column 15. Thus the Cassin formation is now divided between the upper Bascom formation and the Bridport dolomite. The lower Bascom formation contains *Lecanospira* and hence is correlative with the Roubidoux formation of the Ozark region, whereas the upper Bascom contains the Fort Cassin fauna which reappears in the Smithville formation of the Ozark region (columns 52, 53). [J. R.]

Cass Fjord formation. This unit bears a fauna with *Bryograptus*, *Clonograptus*, *Hystricurus*, and *Symphisurina* and is placed by Poulsen (1937; 1946) at the base of the Ordovician. It is recognized in both East and Northwest Greenland. [C. O. D.]

Chambersburg limestone. The Chambersburg limestone of northern Virginia, southern Pennsylvania, and Maryland was formerly interpreted as Trenton (Kay, 1935, p. 231–233, Pl. 22) or upper Black River (Ulrich, 1911; Butts, 1940, p. 195–213). The *Bimuria lamellosa* zone (*Christiania* zone of Bassler) at the top of the Chambersburg seems linked with the Trenton, but much of the formation below this zone seems to be of Black River age. At the type section of the Chambersburg in southern Pennsylvania (Cooper and Cooper, 1946, p. 55–58), the beds referred to that formation are underlain by a dove-colored limestone or calcilutite containing a Lowville fauna. The name is no longer used in Virginia, because the upper part of the Chambersburg has been raised to rank of a formation and the bulk of the formation below this unit has been discovered to be the complex product of two interfingering and transitional facies. [B. C.]

The type section of this limestone has been divided (Craig, 1941) into the Shippensburg, Mercersburg, and "Greencastle" formations; the first two were included in the Edinburg formation by Cooper and Cooper (1945), and the last in the Oranda. The Shippensburg is Bolarian; the Mercersburg, lower Trentonian, is equivalent to the Nealmont limestone of central Pennsylvania. The Oranda seems correlative with the lower Salona of central Pennsylvania and with the Shoreham limestone

of the Trentonian of New York (Kay, 1944). [M. K.]

Chazy limestone. Kay prefers that the rocks younger than the Bridport and Providence Island dolomite, Beekmantown "E", along Lake Champlain, and older than the Black River group be classed as the Chazyan Series. He believes the Chazyan section in New York to be incomplete, as it lies disconformably on the Beekmantown group. [M. K.]

Chickamauga limestone. The so-called Lenoir limestone overlying the Mosheim limestone in the Chattanooga area is quite unlike the Lenoir of the type section or any other Lenoir of east Tennessee. It is also not like the Ridley of the Central Basin of Tennessee to which it was assigned by Butts because of its position above the Murfreesboro. The chert of the two formations is not alike. Actually the "Lenoir" of the Chickamauga section appears to be a continuation of the Murfreesboro formation of the Central Basin which does possess black chert like that of the so-called Lenoir. In the view of G. A. Cooper, therefore, the calcilutite called Mosheim is only another one of those troublesome dove-colored beds misidentified as Mosheim. It is a local facies of the Murfreesboro.

Confirmation of these views is to be seen in the fossils occurring in the shales overlying Butts' Lenoir of the Chickamauga section. These contain a species of *Fascifera* that is very close to *F. stonensis*, a common fossil in the Pierce formation just under the Ridley of the Central Basin of Tennessee. Thus in this Chickamauga section the Pierce-Ridley equivalents occur in a shaly facies. Above these shales Lebanon and Tyrone equivalents occur. [G. A. C.]

"Christiania beds." This informal designation has been used for different portions of the Champlainian Series. The original *"Christiania* bed" was the top division of the Chambersburg limestone, which is now known as the Oranda formation. The name was given to this zone because of the occurrence of a distinctive brachiopod which has since been referred to the genus *Bimuria*. Therefore, this zone should be called the *Bimuria lamellosa* zone.

Another *Christiania* bed characterized by *Christiania subquadrata* occurs in Tennessee and part of Virginia, where it succeeds the true Lenoir. Although above the Lenoir, this *Christiania* zone has for a long time been identified with the Lenoir limestone; more recently a move has been made to call the *Christiania subquadrata* zone the "Upper Lenoir," pending introduction of a new formation name. This *Christiania* zone, considerably older than the Oranda zone, is important to correlations in eastern Tennessee. The entire body of the type Athens falls within the limits of the *Christiania subquadrata* zone, and the Athens traced northeastward from Calhoun, Tennessee, interfingers with the cobbly limestone representing the "Upper Lenoir" at Friendsville, Tennessee. The same *Christiania* zone occurs in the Little Oak limestone of Alabama. The range of the genus *Christiania* in the Appalachians is basal Athens through Oranda. Although the species which led to the name *"Christiania* bed" in the high Chambersburg is now referred to the genus *Bimuria*, a true *Christiania* identified as *Christiania trentonensis* Ruedemann also occurs in the Oranda (Cooper and Cooper, 1946, p. 88). [B. C.]

The lateral gradation of the Lenoir limestone (not just the "Upper Lenoir") into the *Christiania*-bearing Athens suggests that *Christiania* ranges even lower than shown on the chart, into equivalents of the Chazy. Probably it is excluded from rocks commonly classed as Chazy by facies differences. [J. R.]

Collierstown. See Eggleston.

Collierstown limestone. Although recognition of the Collierstown formation has proved useful, some doubt as to its precise age still exists. It is linked with the Oranda to the north and with the Eggleston limestone of Kay to the south. Faunally, the Collierstown is very distinctive, and it is the oldest known Appalachian unit containing the Trenton genus *Rafinesquina* s.s. The Collierstown is not to be confused with another limestone, the St. Luke member of the Edinburg formation, which occurs just below the top of the Edinburg in some parts of the Shenandoah Valley. [B. C.]

Collingwood and Gloucester. Wilson (1938), in the Ottawa Valley, proposed and described the Eastview and Billings formations as rock units which were of Collingwood and Gloucester ages respectively. This action was demanded by the need of rock units in the practical application of the stratigraphy of the Ottawa

Valley. The units were described in final detail in 1946. Accordingly, the names Collingwood and Gloucester were raised to the rank of time terms in the Ontario Ordovician nomenclature. Similar to the procedure in the Ottawa Valley, the proposal of rock unit terms for these respective ages in the Central Ontario succession is under consideration. It should be noted also that strata of these ages are placed in the Upper Ordovician by most Canadian geologists, despite the fact that Raymond (1921), while with the Geological Survey of Canada, placed them in the Middle Ordovician. [B. A. L.]

Cow Head breccia. This phenomenally coarse limestone breccia occurs at the base of the Humber Arm group and in lenses in the lower part of that thick mass of detritals. It consists of angular blocks of underlying sedimentary formations, predominantly of limestone. These masses of breccia have a discontinuous distribution, locally reach considerable thickness, and include blocks as much as 500 feet across. Where thick the breccia shows no internal bedding or sorting. In one locality, a sea cliff at Cormorant Head, its relations to a thrust fault proves that the breccia is a talus or landslide deposit formed at the nose of a thrust which was active during deposition of the Humber Arm shales. Here the interbedded shales bear a pre-Normanskill graptolite fauna including *Phyllograptus*, *Tetragraptus*, *Climacograptus*, etc. [C. O. D.]

Dot limestone. The Dot, Poteet, Rob Camp, and Martin Creek limestones are placed in their present position in column 34 by Cooper and Cooper on the basis of unpublished data. Ralph Miller believes they should be somewhat higher.

Edinburg formation. The Edinburg formation is defined as a unit that embraces the stratigraphic ranges of two interrelated facies of limestone which were formerly thought to be of different ages. It is limited above by the Oranda or Collierstown and below by the Lincolnshire limestone. Considerable variation in thickness and lithology of the Edinburg makes the formation as defined a convenient mapping unit in areas where exposures are insufficient to permit mapping of the component facies tongues individually. [B. C.]

Effna limestone. This unit is approximately the same as the Botetourt limestone member of the Edinburg formation, but unlike the Botetourt it is characterized by reefy inclusions of coarse-grained limestone or calcarenite. However, not all of the Effna limestone is reefy or biohermal, and, locally, black shale and limestone of Liberty Hall facies or nodular impure limestone like the "Upper Lenoir" limestone at Friendsville, Tennessee, compose much of the formation. The calcarenitic limestones are localized deposits of abundantly fossiliferous material deposited in bioherms or along their margins during early stages in the deposition of the Liberty Hall black sediments and clayey limestones of the "Upper Lenoir." The Effna reefs and banks of calcarenite are of economic importance because of the high purity of the limestone composing them. The Porterfield Quarry of the Mathieson Alkali Works, 4–5 miles east of Saltville, Smyth County, and McNutt Quarry, near Sharon Springs, Bland County, both in Virginia, are notable examples of the utilization of this peculiar limestone. It is also noteworthy that the brachiopod, trilobite, and bryozoan faunas of the Effna bioherms exhibit some very rare genera which are unknown in other facies. [B. C.]

Eggleston formation. The typical Eggleston of Giles County, Virginia, is a post-Moccasin formation composed of impure limestones and altered volcanic ash beds. The type Eggleston contains unequivocal Curdsville fossils which place the formation in the, lower, though not basal, Trenton. The Eggleston contains intercalated layers of Collierstown limestone in Bath and Alleghany counties, Virginia, and in neighboring sections of West Virginia, which serve to tie it with the beds between the Edinburg and Martinsburg formations of the Shenandoah Valley belts of outcrop.

Introduction of the name Eggleston for a bentoniferous succession in Lee County, Virginia (Huffman, 1944, p. 145–174; Miller and Fuller, 1944; Miller and Brosgé, 1950) is unfortunate, and further use of this name in the Powell Valley district should be discontinued. In the Rose Hill-Hagan district of Lee County, the so-called Eggleston contains a Lebanon-Carters or pre-Curdsville fauna which is quite different from that in the type Eggleston. The name Tyrone is more accurate for this unit because some Tyrone fossils occur in

it. On the other hand, the lithology and limits of the unit in Lee County probably are not precisely the same as in central Kentucky, and therefore a new name for the Lee County division might be warranted. For the chart, Carters limestone is used. [B. C.]

Kay considers the Eggleston to extend to the base of metabentonite V-6 at Narrows of the New River and to be equivalent to the Middle Nealmont; and the Collierstown to include a basal 10 feet of beds having *Tetradium* sp. aff. *T. fibratum*, which zone lies in the middle of the Eggleston of Bath County, Virginia. [M. K.]

Ellis Bay formation. The Ellis Bay formation (Towenhofel, 1928) of Anticosti contains many species not elsewhere known in North America and is considered to represent the highest Richmond known on the continent. Corals which are common in the English Head and Vauréal formations are abundant, together with others not elsewhere known in the continent. There are several species of Silurian affinity, and associated with them are some forms which if found alone would lead to assignment of the formation to the Trenton. [W. H. T.]

El Paso formation. Unit A (Cloud and Barnes, 1949, p. 74) is the zone of *Diaphelasma*; Unit B, the zone of *Ceratopea* and *Archaeorthis*, is divisible into three subzones—a lower subzone of *Orospira* and *Xenelasma*, a middle subzone of *Polytoechia*, and an upper subzone of *Polytoechia* and *Hesperonomia*; Unit C is the zone of *Syntrophopsis magna*. [C.O.D.]

Elway limestone. The beds of this formation were originally included in the Blackford formation (Cooper and Prouty, 1943), but subsequently it has been found that the distinctive Elway fauna is very closely related to the Lincolnshire limestone. In Tazewell and Russell counties, Virginia, the Elway and Lincolnshire are separated by a distinctive calcilutite known as the Five Oaks limestone, but southwest of Lebanon, Virginia, the Five Oaks limestone passes into cherty rock containing Elway fossils. Where the Lincolnshire and Elways are in juxtaposition, the two are not easily distinguished. The fauna of the Elway is quite unlike that of the Blackford, and this is considered additional reason for giving the Elway beds formation rank. [B. C.]

Ely Springs dolomite. The Ely Springs formation of the Pioche district of Nevada (Westgate and Knopf, 1932) carries a fauna of Richmond age (Kirk *in* Wilmarth, 1938) which belongs to the Arctic invasion of late Ordovician time. [W. H. T.]

English Head formation. The English Head formation of Anticosti Island consists mainly of calcitic limestone and carries a fauna including species of Trenton affinities and typical Richmond species. As the formation very definitely lies some distance above the Makasti black shale, an eastward extension of the Collingwood of Ontario, the position is certainly above the Trenton, and the species of Trenton affinities are evidently holdovers. The English Head fauna finds its nearest correlative in the Red River and correlative formations in Arctic Canada and western North America. [W. H. T.]

Eureka quartzite. The dating of this formation has long presented difficulty since no fossils have been found in its type area. Recently C. W. Merriam discovered yellow limestone and dark shale on Martins Ridge in the Monitor Range west of Eureka, Nevada, which he interpreted as facies of the Eureka quartzite. These beds are sandwiched between a lower 25-foot sandstone and the main mass of the Eureka. These yellowish beds have *Sowerbyites* in abundance and are therefore about equivalent to the Lincolnshire in age. The dark shaly beds above the yellow limestone contain a fauna including *Reuschella* and *Cryptolithus*. This combination suggests the Oranda fauna of Virginia. The evidence cited thus indicates that the main mass of the Eureka quartzite lying on an Oranda equivalent is at least of Middle or Upper Trenton age. [G. A. C.]

The name Eureka has been applied through western Utah and eastern Nevada to two quartzites, of which the upper is the principal quartzite in the Eureka district, Nevada. The lower quartzite grades westward into more calcareous beds having Chazyan faunas and underlies *Sowerbyites*-bearing argillaceous beds in central Nevada. The upper quartzite, the typical Eureka, succeeds calcareous argillites with a medial Trentonian (Denmarkian) fauna, like that in Salona beds near Antioch in Virginia, in the Antelope and Monitor ranges in central Nevada (Hintze and Webb, 1950). [M. K.]

Fish Haven dolomite. The Fish Haven dolomitic limestone seems to be unconformable

upon the underlying Swan Peak quartzite. According to Richardson (1913) it carries a Richmond fauna. [W. H. T.]

Five Oaks limestone. The Five Oaks limestone is a high-calcium calcilutite between the Elway and the Lincolnshire limestones in western belts of the Appalachian Valley. A considerable part of the Elway limestone is like the Five Oaks, except that it contains abundant chert which makes up as much as 50 per cent of the rock. It seems likely that the Five Oaks formation is simply Elway limestone without chert, and recent field work by the writer in western Virginia demonstrates that the cherty rock and high-calcium calcilutite grade into one another. The establishment of this stratigraphic relationship is of importance because the Five Oaks limestone has been confused with the Mosheim limestone of Tennessee (Cooper and Prouty, 1943). The real Mosheim of Tennessee is a localized facies of the Lenoir limestone. The Lenoir beds just above the Mosheim interfinger with the Blackford red beds which occur considerably below the Five Oaks limestone. Thus the Five Oaks and the Mosheim are not the same formation. [B. C.]

Fremont limestone. The Fremont limestone, according to Kirk (Kirk *in* Wilmarth, 1938), carries a Richmond fauna in all except the lowest 10 feet. The formation correlates with the Red River formation of Canada and the English Head of Anticosti. [W. H. T.]

See Red River formation.

Galena limestone. Twenhofel would remove the Stewartville and Dubuque from the Trenton and place them in the Cincinnatian but below the Maquoketa. Many elements of the fauna have a Trenton aspect, but the presence of *Halysites* and some of the cephalopods are indicative of the Richmond. Twenhofel considers that the Stewartville and Dubuque correlate with the Red River and correlative formations of the Arctic invasions into western North America, all of which he assigns to the Richmond, following Miller, Roy, Foerste, Hussey, and others. Kay (1935) correlated the Dubuque with the Collingwood, but Stauffer and Thiel (1941) and Ulrich (1924) place it in the Maquoketa. Ulrich also placed a stratigraphic break between the Dubuque and Stewartville of which Twenhofel doubts the existence. [W. H. T.]

Garden City limestone. Fossils collected in the lower beds of this formation contain *Nanorthis* and *Apheoorthis*, a combination seen elsewhere in the lower Pogonip of Nevada, in the basal Manitou limestone of Colorado, in the Grove limestone of Maryland, and seemingly indicative of basal Ordovician. The upper part of the Garden City formation contains the brachiopod *Hesperonomia* and the trilobite *Kirkella vigilans* (Whittington). These suggest affinities with the Black Rock formation of Arkansas at the top of the Canadian. [G. A. C.]

Reuben Ross (1949) has studied the trilobites of this formation and recognized 12 faunal zones which indicate that the Canadian Series is fully represented. Near the base is a Tribes Hill fauna with the genera *Bellefontia*, *Clelandia*, *Histricurus*, *Xenostigium*, and *Symphisurina*; and near the top there is both lithologic and fauna transition to the overlying Swan Peak formation of Chazyan age. [C. O. D.]

Girardeau limestone. The age of the Thebes sandstone, the Orchard Creek shale, and the Girardeau limestone is still a moot question; they may belong at the base of the Silurian. Savage (1913) originally assigned the first two to the Richmondian and the Girardeau to the base of the Silurian. He later (1917) shifted the Orchard Creek shale to the Silurian because nearly half of its fauna ranges up into the Girardeau. On the contrary, Weller (1939, p. 56) stated that the Orchard Creek shale is a southward continuation of some part of the Maquoketa formation, that there is no sharp break between it and the Girardeau limestone, and that both are possibly Ordovician. In the type region of both in southeastern Missouri, the contacts appear to be gradational between Thebes sandstone and Orchard Creek shale, whereas the Sexton Creek limestone overlies the Girardeau with conspicuous erosional unconformity and oversteps far beyond it. The problem is now under study by John Gealy. [C. O. D.]

Glenogle formation. Limestones in the lower part of the formation (Walcott, 1924; 1928), according to Kirk (1934), correlate with the *Piloceras-Calathium* zone of the El Paso limestone and is of middle Canadian age. [W. H. T.]

Glenogle shale. Dark shales in this formation contain abundant graptolites. Extensive collections made by Walker from the Windemere sec-

tion were studied by Ruedemann who concluded that the faunas are closely allied to those of the Deepkill shale in New York and that in spite of the fact that the formation is 2162 feet thick it represents only zones 1, 2, and 3 of the Deepkill sequence. However, in the light of faunas from other localities Ruedemann later (1947, p. 105) concluded that the Glenogle shale contains a full series of both Deepkill and Normanskill graptolite faunal zones. [C. O. D.]

Gloucester shale. *See* discussion under Collingwood.

Gratton limestone. The Gratton limestone was originally thought to be older than the Wardell limestone, but a restudy of the Tazewell County sections suggests that the Gratton and Wardell grade laterally into one another. This conclusion is supported by the occurrence of a bioherm of calcilutite in the upper part of the Wardell limestone near Snowflake, Scott County, Virginia. [B. C.]

Green Point shale. South of Bonne Bay and north of Table Head the Canadian Series is well developed in the calcareous facies (St. George formation), but in the intervening area it is detrital and for the most part comprised of dark graptoliferous shales. These shales are of great but undetermined thickness and are complexly crumpled and faulted. A tear fault of great throw separates the detrital from the calcareous facies midway between Green Point and the entrance to Bonne Bay. Relations at the north are unknown, but, since the change in facies is abrupt there also, another tear fault is likely. It is believed that the detrital facies has been thrust over the calcareous facies from an original site considerably farther east.

The name Green Point shale was applied to the whole of this detrital complex by Schuchert and Dunbar (1933), but they found fossils only at Green Point. There the fauna includes *Dictyonema flabelliforma* var. *angelica* and *Staurograptus* and is clearly of lowermost Canadian age.

Johnson (1941, p. 143) studied the long section exposed along the north shore of western Brook Pond and found graptolites in various places, some of which correlate with middle Deepkill, and others high Deepkill and basal Normanskill beds. On this basis he subdivided the Green Point shale of Schuchert and Dunbar into three formations, restricting the name Green Point to the lowest. The divisions are thus:

St. Paul's group—Upper Deepkill and basal Normanskill

Western Brook Pond group—Middle Deepkill

Green Point shale—basal Deepkill

As indicated by Ruedemann (1947, p. 60), Johnson's collections show that the upper two groups are in part equivalent. Much more work is needed to establish the natural stratigraphic units in this shale sequence. [C. O. D.]

Harding sandstone. The Harding sandstone of Colorado is overlain by the Fremont limestone, apparently without stratigraphic break, and it is unconformable upon the underlying Manitou limestone (Walcott, 1892). Kirk (1930) assigned the Harding sandstone to the Trenton, but, unless it can be shown that a stratigraphic break lies above it, Twenhofel is of the opinion that it is best allied with the overlying Fremont limestone and considered the initial deposit of that formation. [W. H. T.]

On the contrary Kirk cites the presence of *Echinosphaerites* and on the basis of this and other fossils concludes that the sandstone correlates with part of the Kimmswick limestone and is not younger than early Trenton beds. [C. O. D.]

Hermitage limestone. The Hermitage limestone of Tennessee includes the Curdsville (C. W. Wilson, 1938; 1939). It is present marginal to the Nashville Dome but absent in the central basin of Tennessee. It is McFarlan's opinion that the Jessamine limestone of Kentucky is also represented in Tennessee in the upper Hermitage. [A. C. McF.]

Holston limestone. The name Holston has been applied to many different zones of pinkish to gray coarse-grained crinoidal limestone. The term has been so loosely used that it no longer has any specific stratigraphic significance. The fact that the name is so closely associated with the lithology of the widely quarried Tennessee marble makes it a suitable name for a facies of the Champlainian Series abundantly developed in eastern Tennessee and southern Virginia. Holston-type limestones make their first stratigraphic appearance just above the Knox group and range upward to the base of the Moccasin formation. The maximum development of the facies occurs in the Clinch Mountain belt of

outcrop between Thorn Hill and Luttrell, Tennessee. The same type of limestone occurs farther north in the Appalachian Valley. At Lexington, Rockbridge County, it composes the Murat calcarenite lenses in the Lincolnshire limestone. The same kind of limestone occurs in the Valcour division of the New York Chazy. [B. C.]

The Holston limestone, shown in Column 38, occurs also at Friendsville (Col. 36) between "Upper Lenoir" and "Tellico." The Holston is a perfectly usable formation in the Knoxville area and to the southwest, and it can be mapped consistently, in the belts represented by columns 38 and 36, between the Lenoir limestone (or the equivalent Athens shale) below and the Ottosee shale above, provided it is realized that the Holston includes both a red lime-sandstone facies (typical "marble") and a red limy quartz-sandstone facies (so-called Tellico of these belts; *see* Tellico sandstone). That the name Holston (likewise Ottosee) has been misused hardly seems an adequate reason for rejecting it. I believe the Holston is roughly equivalent to the Lincolnshire limestone. J. R.]

See also Lincolnshire limestone.

Humber Arm group. The Humber Arm group (Schuchert and Dunbar, 1934, p. 88–98) includes dark shales with interbedded siltstone, alternating with greenish-gray sandstone, and, locally, with pyroclastics and pillow lavas. It reaches a great but undetermined thickness and has yielded but few fossils, all of which are from near its base. It succeeds the Table Head formation with a profound change in lithology but probably without a hiatus, the change being due to disturbance to the east and to thrust faulting within the area of deposition. Its base is probably not younger than uppermost Chazyan, but the age of its upper limit is entirely problematic. [C. O. D.]

Joins formation. This formation has been variously assigned to the Chazyan and to the Canadian. The presence of *Didymograptus artus* is a link to the latter division. In contradiction to this correlation is the presence of the brachiopods *Desmorthis* and *Anomalorthis*, which suggest a higher position. In central Nevada, where *Desmorthis* is abundant, it overlies a considerable thickness of post-Canadian rocks. Here a thick sequence containing the brachiopod *Orthidiella*, the snail *Palliseria* (=*Mitrospira*), large *Maclurites*, and *Receptaculites* is succeeded by beds with *Desmorthis* and *Anomalorthis*. This thick sequence is missing in Oklahoma. The *Desmorthis-Anomalorthis* zone is linked to still higher rocks that contain *Pliomerops* and are clearly related to the Oil Creek formation. On paleogeographic and paleontological grounds the *Desmorthis* zone seems to be post-Canadian. [G. A. C.]

Juniata sandstone or *formation.* In middle belts of the Appalachian region, the Juniata formation succeeds the *Orthorhynchula stevensoni* zone of the Martinsburg formation without any evidence of a hiatus. In southern Pennsylvania, Maryland, and northern Virginia, the Martinsburg formation is succeeded by the Bald Eagle conglomerate or Oswego sandstone, one or the other of which underlies the Juniata as recognized in those districts. Butts (1940) has postulated the existence of an unconformity in those areas where the Juniata succeeds the Martinsburg; but it is fully as likely that the Juniata facies includes correlatives of the Bald Eagle and Oswego where those formations are not recognizable. [B. C.]

Kinnikinic quartzite. The Kinnikinic formation (Ross, 1934), composed entirely of quartzite with a thickness of 3500 feet, has yielded no determined fossils, and its exact position is unknown. Lithology suggests correlation with the Eureka quartzite of Nevada, but as it underlies the Saturday Mountain formation of probable Richmond age it should be placed in that division of the Ordovician. It may hold a lower position. [W. H. T.]

The Kinnikinic formation resembles the Eureka quartzite in lithology, and, like the latter, it is thick and implies active erosion and the transportation of much sand. On the contrary, the Bighorn and its equivalents spread over a peneplaned surface of very great extent. This suggests a regional environment very different from that of the Kinnikinic formation but like that of the Eureka quartzite which is dated by fossils. [C. O. D.]

Kirkfield formation. The original definition of the term Kirkfield by Johnston (1911, p. 189) reads as follows.

"Kirkfield limestone (group) (new); the upper portion only included in the Trenton [i.e. in the Sherman Falls]. The lower portion includes the

Crinoid and Dalmanella sancti-pauli beds which are below the base of the typical Trenton [i.e. the Sherman Falls] in New York state."

In his table of formations the Kirkfield limestone is shown to rest on the Coboconk limestone with an intervening hiatus, and to be overlain by Pleistocene till.

From detailed stratigraphic investigations it is now known that the succession in the type area includes the following units, in descending order:

8. *"Hormotoma* and *Fusispira"* beds
7. *"Rafinesquina deltoidea"* beds } = Cobourg ls.
6. *"Prasopora* beds", 200 feet thick, but of which only the basal 6 ft. is present in the quarry at Kirkfield..... = Sherman Fall ls.
5. "Crinoid beds" in the middle of the Kirkfield quarry.
4. *"Dalmanella sancti-pauli"* beds exposed in the basal part of the Kirkfield quarry.
3. "Transition beds" of dense, sparsely fossiliferous limestone.
2. Calcarenite beds equivalent to those bearing the fauna of Paquette Rapids.
1. Coboconk limestone, the *"Columnaria* beds" of authors.

It is not clear from his brief discussion that Johnston saw, or distinguished units 2 or 3; but he writes "In view of the fact that both the Crinoid and the Dalmanella sancti-pauli beds of south-central Ontario [i.e. units 4 and 5] are older than the base of the typical Trenton [i.e. the Sherman Falls] in New York state * * * this series of limestones [units 4, 5, and 6] has been provisionally named the Kirkfield limestone group, from the village of Kirkfield, in the county of Victoria, near which they are best exposed."

In Central Ontario, Kay (1937, p. 590) regarded the Coboconk strata as equivalent to the upper member (Napanee) of the Rockland limestone and assigned the overlying "Transition beds" and those of the Kirkfield quarry (units 4, 5, and 6) to the Hull formation. In 1942, Sinclair questioned correlation of the "Crinoid beds" and the *"Dalmanella sancti-pauli"* beds with the Hull. In 1943, Kay replaced the name Hull in the standard section by Kirkfield, retaining the name Rockland for the underlying unit of the Trenton stage. Sinclair (1953) on the contrary believes the beds of the Kirkfield quarry to be equivalent in age to the Rockland beds of the Ottawa Valley and thinks the Hull formation may not be represented in Central Ontario. Redefinition of the term Kirkfield so that it will comprise the beds in Central Ontario between the top of the Coboconk and the base of the Sherman Fall limestone is under consideration. If this were done the term Hull would not be used in this area.

Lebanon limestone. For many years the Lebanon limestone of the Stones River group of central Tennessee was considered Chazyan; but actually it is clearly younger than the Chazy and is probably of late Black River age. At the present time confusion still exists regarding the correlatives of the late Black River Chaumont limestone and the early Trentonian Rockland limestone of the New York section. The strong similarity of Chaumont and Rockland faunas makes those two formations difficult to differentiate, and from a practical standpoint it is to be lamented that the lower Trenton boundary is placed at the base of the Rockland, rather than at the base of the Trenton as it is exposed at Trenton Falls, New York. Although on the chart the Lebanon limestone is shown in the position of the upper Black River beds, its upper part may range up into the lower Trenton in central Tennessee. The Nealmont limestone of central Pennsylvania, which Kay places in the lower Trenton (Rockland), is faunally and lithologically like the Lebanon, and it is not unlikely that the two formations are at least partially equivalent.

B. N. Cooper (1945, p. 272) correlated the Lebanon limestone with the Witten limestone of the Appalachian Valley. Further study of these two formations makes it necessary to qualify that correlation. The Witten is a persistent eastward-stretching lower tongue of the Lebanon limestone of the Central Basin of Tennessee. Other tongues of Lebanon limestone occur within the Moccasin formation as developed in the vicinity of Rose Hill School, Union County, Tennessee. In the Rose Hill-Hagan area of Lee County, Virginia, a few feet of fossiliferous limestone of distinctly Lebanon aspect occurs within the 150 feet of limestone identified by Huffman and by Miller as Eggleston. Thus the Lebanon of Central Tennessee is more than a Witten correlative. Kay has established the

facies equivalency of the Nealmont limestone of central Pennsylvania to the Moccasin formation of western Virginia. From another direction, the Lebanon has been traced into the Moccasin, so that at least a part of the Lebanon corresponds to the Nealmont limestone. [B. C.]

Lenoir limestone. The type Lenoir limestone of the Lenoir City-Philadelphia belt of eastern Tennessee consists of three distinct zones. The lowest zone is impure earthy limestone with abundant *Rostricellula "pristina"*; the middle portion is impure shell limestone containing *Mimella nuclea* and *Billingsaria parva*; and the top unit is dark-gray cherty limestone containing a profusion of *Maclurites magnus*, though apparently few other fossils. At Friendsville, Blount County, Tennessee, this entire body of rock is succeeded by nodular limestones containing *Christiania subquadrata*, *Calliops declivis*, and numerous other fossils not found in the typical Lenoir. The nodular *Christiania*-bearing beds were classed with the Lenoir, although faunally and lithologically they are quite easily distinguished from the subjacent Lenoir. The *Christiania* beds are now tentatively referred to as "Upper Lenoir," signifying that no correlation with the real Lenoir is implied.

The beds which Butts (1940, p. 139–148) called Lenoir in Virginia include more than the equivalent of the type Lenoir, and in many sections—for example in the Clinch Valley district (Cooper and Prouty, 1943, p. 847–861) and in the Shenandoah Valley (Cooper and Cooper, 1946, p. 51–53)—the beds he assigned to the Lenoir are all younger than any part of the type Lenoir. The errors in identification came about through misidentification of the Mosheim limestone. Several different dove-colored limestones or calcilutites were called Mosheim, and the dark-gray limestones succeeding them were called Lenoir by reason of their superposition with respect to the supposed Mosheim. [B. C.]

Perhaps the so-called "Upper Lenoir" at Friendsville (Col. 36) is a *Christinia*-bearing facies intermediate between the Athens "shale" and the typical *Maclurites*-bearing upper Lenoir at Lenoir City (Col. 38). In any case, the "Upper Lenoir" at Friendsville underlies Holston "marble." [J. R.]

Lincolnshire limestone. This limestone is tentatively correlated with the upper Chazyan, but the faunal evidence is not wholly conclusive. West of Lexington, Virginia, it has an intercalated mass of coarse-grained limestone, the Murat calcarenite, in which there are many characteristic Chazyan trilobites, including *Pliomerops*, *Sphaerexochus*, *Acrolichas*, and *Illaenus*. Faunally and lithologically this unit resembles the typical Chazyan of Valcour Island. *Maclurites magnus* also occurs in the Lincolnshire limestone, though it is much more common in the upper part of the typical Lenoir limestone. On the other hand, the most characteristic elements of the Lincolnshire fauna, notably *Sowerbyella*, *Sowerbyites*, and *Dinorthis*, are unknown in the type Chazyan of the Champlain Valley. It seems possible that the cherty Lincolnshire facies represents an environment inhospitable for the typical Valcour fauna. [B. C.]

The Lincolnshire limestone (Cooper and Prouty, 1943) is classified by Kay as late Chazyan because the fauna of the reefs in its upper part in Monroe County, West Virginia, and Allegheny and Bath counties, Virginia, has similarities to that in reefs within the Valcour limestone of Grand Isle County, Vermont. Inasmuch as the facies is of limited stratigraphic range in each region, there is no control to indicate that the two regional occurrences are closely synchronous. The Lincolnshire lies disconformably on the Five Oaks limestone and is succeeded by regional unconformity along the Allegheny front in Virginia and West Virginia (Kay, 1947). [M. K.]

Comment on Rodgers' correlation of the Holston marble of the Knoxville area is necessary. Rodgers' diagram (Fig. 1) shows the Holston marble overlying the *Christiania* beds of the Upper Lenoir formation. The Lincolnshire, however, has never been seen by G. A. Cooper in such a position. In all occurrences known to Cooper the Lincolnshire *underlies* beds containing *Christiania* or equivalents of the *Christiania* beds.

Exposures at Whitesburg and St. Clair in the Bulls Gap region, Tennessee, make it clear that the *Christiania* beds of the Upper Lenoir are closely related to the restricted Whitesburg and Botetourt limestone of Virginia. Lower Edinburg abounds in *Christiania* and is the equivalent of the Whitesburg and Botetourt; lower Edinburg overlies Lincolnshire. No paleontological evidence is known to Cooper to support

a correlation of the Holston and Lincolnshire. [G.A.C.]

Liskeard formation. The Liskeard formation consists in ascending sequence of a Red Shale member without fossils, a Lower Sandstone member with many fossils among which are *Halysites* and *Plasmopora*, a Lower Green Shale member, an Upper Red Shale member, and an Upper Limestone member designated the *Maclures* zone in which are numerous fossils of Richmond aspect. The Richmond fossils are associated with others (*e.g.*, cystids) of Trenton affinities. Hume (1925) correlated the formation with the Trenton, but the occurrence of Richmond fossils like *Halysites*, *Plasmopora*, and others hardly permits such assignment. The faunal association is similar to those of the Red River formation of Manitoba and the English Head formation of Anticosti. The formation is placed in the Richmond. [W.H.T.]

Little Oak limestone. Numerous fossils collected from the Little Oak formation establish beyond doubt its correlation with the *Christiania* beds of the "Lenoir" ("Upper Lenoir"). Nevertheless it is important to point out a situation that involves several other formations. At Pratts Ferry, 18 miles southwest of Montevallo, Alabama, the upper hard limestone of the Lenoir (Butts) abounds in *Christiania*. On these beds occurs a thin limestone containing fossils suggestive of the Whitesburg limestone (of Butts, not Ulrich). On this thin limestone lies black shale containing *Nemagraptus* and many other graptolites of the Normanskill assemblage. This section thus clearly shows that the position of *Nemagraptus* is well within the *Christiania* zone. A similar situation exists in the type Athens belt of outcrop from Athens to Calhoun, Tennessee. [G.A.C.]

Long Point formation. This formation comprises a slender fault block that makes up Long Point Peninsula west of Port au Port Bay. Here it has a thickness of 1500 feet and is, in part, richly fossiliferous. Its fauna, including *Hesperorthis*, *Glyptorthis*, *Valcourea*, *Multicostella*, *Sowerbyites*, *Öpikina*, *Rafinesquina*, and *Gonioceras*, indicates late Black River or early Trenton age. [C.O.D.]

Lowville limestone. Much confusion has arisen from misidentification of the Lowville limestone equivalent in the Appalachian Valley. For many years it was erroneously assumed that the Lowville, "birdseye limestone", lithology was all of the age of the Lowville formation of New York State. It was also argued that the Lowville fauna was limited in its range to this horizon (Butts, 1928, p. 365), and that certain fossils such as *Tetradium cellulosum* and *Cryptophragmus antiquatus* were excellent Lowville guide fossils. In Lee County, Virginia, the 1000 feet of limestone which Butts (1940, p. 187) assigned to the Lowville contains equivalents of the entire succession from the base of the Benbolt to the top of the Moccasin formation (Huffman, 1945, p. 145–174). This dove-colored limestone facies has considerable stratigraphic range in the eastern United States, and the types of fossils found in it characterize the "birdseye" limestone facies regardless of stratigraphic position within the Champlainian Series.

Ulrich (1911) long recognized as Lowville the limestone just beneath the base of the *Echinosphaerites* beds of the Chambersburg formation. At the type locality of the Chambersburg limestone, near Marion, Pennsylvania, this supposed Lowville equivalent contains a considerable number of fossils unknown from beds older than the Pamelia-Lowville succession of New York (Stose, 1909; Cooper and Cooper, 1946, p. 69–70), and here it is underlain by 1000 feet of Champlainian limestones of which a considerable part shows unmistakable Chazyan affinities. Furthermore, the succession which overlies the *Tetradium*-bearing dove-colored limestone bears the faunal stamp of the Black River and Trenton. Of all the zones in the Champlainian Series of the Appalachian Valley, which have been identified as Lowville or Pamelia-Lowville equivalents, this dove-colored limestone below the type Chambersburg probably comes closest to being a valid correlative of the lower Black River of New York.

One of the puzzling features of the Champlainian section of the Marion, Pennsylvania, area is the occurrence of this Lowville-type limestone at precisely the same stratigraphic position as is occupied farther south by the Lincolnshire limestone of the Shenandoah Valley of Virginia. The establishment of a reliable Chazy-Black River boundary in the Appalachian region awaits further study of the Lincolnshire and its equivalents. [B. C.]

McMillan formation. The three divisions of the McMillan formation of the central Bluegrass region are not to be considered as individually the precise correlatives of the three well-known divisions of the McMillan of the Cincinnati region. In much of the southern Bluegrass country fossils are sparse in the Tate member, but they become abundant northward on both sides of the arch. The Gilbert member is limited, as a distinct lithologic unit, to the southern Bluegrass region. On the eastern side of the arch in Montgomery and northern Bath counties, the characteristic *Monticulipora molesta* zone (Bellevue) appears at the bottom of the Tate member. Northward, it ranges somewhat higher in that unit. Ranging through the Tate member and in the Sunset member of the Arnheim formation is the abundant *Amplexopora robusta* associated with *Platystrophia ponderosa*.[6] At Maysville, the section approximates the normal Cincinnati succession. In the western area of outcrop in Kentucky, further work is needed. According to Butts (1915), the Arnheim formation rests unconformably on the Bellevue formation at Sulphur in Henry County and at Madison, Indiana, but McEwan (1920) showed that both Corryville and Mount Auburn beds are present at Madison. It is probable that the entire McMillan unit is represented in this western area but is sufficiently different faunally so that the Cincinnati zones cannot readily be carried throughout. [A.C.McF. and E.R.C.]

Manitou formation. The Manitou formation (Cross, 1894; Kirk, 1934) of the Front Range of Colorado is a limestone which according to Kirk seems to correlate with the *Piloceras-Calathium* zone of the El Paso limestone although *Calathium* has not been found. [W.H.T.]

Marathon limestone. P. B. King (1937, p. 26–30) described this formation and cited graptolites from numerous localities indicating that it spans the full range of the Deepkill faunal zones. Ruedemann (1947, p. 98) also lists graptolites and concludes that "The Marathon formation would thus seem to compass the entire Deepkill graptolite shale corresponding to the entire Canadian and probably also the Lower Chazy." The Monument Springs dolomite member in the lower part of the formation contains *Calathium*, *Piloceras*, and *Colpoceras* and is correlated by Kirk (1934) with some part of the lower half of the El Paso limestone. [C.O.D.]

Martinsburg shale and formation. The Martinsburg formation in the type area of eastern West Virginia and southern Pennsylvania is the youngest Champlainian formation in the Massanutten syncline, and, insofar as known, all the type Martinsburg is Trenton. Eden and Maysville equivalents elsewhere classified with the Martinsburg are unknown in the type area. The Martinsburg facies makes its first appearance at somewhat lower stratigraphic levels on the southeastern side of the Appalachian Valley than in median and northwestern belts of outcrop. Thin tongues of Martinsburg siltstone and shale make conspicuous partings in the lower beds of the Edinburg formation in Shenandoah Valley, and wherever these intercalations are found the included fossils are more like those in the higher Martinsburg formation than the fossils of the inclosing Edinburg limestones. [B.C.]

The "Martinsburg" shale of eastern Pennsylvania contains beds with Deepkill graptolites (Stose, 1930); these were recognized as anomalous by Willard (1943) and have been considered to be in a thrust sheet of Cambrian and Ordovician slates, similar to the Taconic sequence in New York (Stose, 1947). The section in column 20 is that of Martinsburg shale stratigraphically succeeding the Jacksonburg limestone (Miller, 1937), not that in the "Hamburg Klippe" of Stose. [M.K.]

Matapedia group. These beds, exposed in Matapedia Valley at the head of Bay Chaleur, consist of dark slates, quartzites, and argillaceous limestones. In limestones, appearing in the upper part, Crickmay (1932, p. 337–378) found fossils proving equivalence with the Whitehead formation. The lower beds are unfossiliferous, and the age of the lower limit is uncertain. [C.O.D.]

Maysville-Richmond beds of Central Kentucky. In the Cumberland River region of southern Kentucky, the essentially barren dolomitic strata of Maysville-Richmond age rest on the Leipers shale. Recent re-examination of this section by McFarlan and W. H. White shows a conformable sequence from Leipers through Tate-Mt. Auburn and Arnheim and locally the

[6] *See* notes on the Maysville-Richmond boundary.

Waynesville. The thickness of the sequence varies irregularly beneath the Chattanooga shale, and in many places only the Tate (McMillan) is present. [A.C.McF.]

Mazourka formation. The Mazourka formation of the Inyo Range of California (Phleger, 1933) lies conformably upon the "Pogonip" formation. It consists of slates and quartzites and carries a fauna which Phleger assigns to the Chazy. [W.H.T.]

Mictaw group. The Mictaw group of black shales, greenish-gray sandstone, arkose, and tuffaceous graywackes has a great but undetermined thickness. These beds are much deformed and sparsely fossiliferous. Northrop (1939, p. 11) cites graptolites studied by Ruedemann indicating zones ranging in age from Black River to Eden. [C.O.D.]

Mingan limestone. The Mingan formation (Twenhofel, 1938) consists of calcitic limestones which lie unconformably on the Romaine formation. It carries a typical Chazyan fauna in which some elements suggest the Black River. [W.H.T.]

Moccasin formation. It has been shown (Cooper, 1945, Pl. 9) that the type Moccasin is post-Witten and pre-Curdsville in age. Beds of Moccasin facies, however, make their first appearance in the Bowen formation, which underlies the Witten in the Clinch Mountain belt of outcrop. Thinner tongues of red mudstone, representing the Moccasin facies, occur nearly 200 feet below the base of the Witten limestone in Lee County, Virginia.

The age of the Moccasin formation has not yet been satisfactorily established. In the Powell Valley district near Rose Hill School, Union County, Tennessee, the Moccasin red beds interfinger with the Lebanon limestone which is believed to be of late Black River age. Farther north in the western Ordovician belts of Virginia in Giles, Alleghany, Bath, and Highland counties, the Moccasin formation contains interbeds of limestone which Kay (1944, p. 108–109; 1947, p. 1188-1189) correlated with the Nealmont limestone of Pennsylvania, which he believes to be of early Trenton age. As indicated under the discussion of the Lebanon limestone, the faunal differences between supposed late Black River or Chaumont beds and early Trenton or Rockland strata do not seem very real. The Lebanon and Nealmont are faunally quite similar, but the former we believe to be late Black River, whereas Kay believes the Nealmont to be early Trenton or Rockland. Thus the age relations of the Moccasin red beds cannot be satisfactorily established until Lebanon-Nealmont correlations are better understood. [B.C.]

Kay (1947) considers the upper 20 feet of the type Witten limestone (Cooper and Prouty, 1943) to be lower Trentonian, and to pass conformably into the "red marble" member of the basal Moccasin. The Moccasin intertongues with the lower Trentonian, Nealmont, limestone northeastward. [M.K.]

Mons limestone. The Mons formation of western Canada is a limestone (Walcott, 1924; 1928; Kirk, 1934) which according to Kirk contains *Calathium* in its lower part and is therefore of Canadian age. Also, according to Kirk, the *Piloceras-Calathium* zone of the El Paso limestone correlates with the upper Mons. [W. H. T.]

Montoya limestone. The Montoya formation immediately overlies the El Paso limestone and originally was included with it. The upper part of the formation carries fossils characteristic of strata in the Rocky Mountain region generally assigned to the Richmond. According to Ulrich (*in* Wilmarth, 1938) the lower part carries Galena fossils. The formation is considered to have been deposited during the late Ordovician invasion of the continent by waters originating in the Arctic. In these waters lived holdovers of Middle Ordovician time in association with organisms typical of early Richmond time. [W.H.T.]

Mosheim limestone. The type Mosheim of Tennessee is a localized dove-colored limestone facies in the lower part of the Lenoir limestone (Cooper and Cooper, 1946, p. 51-52). Where the Mosheim limestone is recognizable, it is succeeded by either middle or upper Lenoir beds. Several other zones of dove-colored limestone have been confused with the typical Mosheim of Tennessee. In Tazewell County, Butts (1932; 1940) identified two different limestones as the Mosheim equivalent. Later work (Cooper and Prouty, 1943, p. 852–853) showed these supposed Mosheim equivalents to be at different stratigraphic levels separated by at least 400 feet of beds. [B.C.]

The Mosheim limestone of the type locality

(near Col. 35) and of the Knoxville area is a massive aphanitic limestone facies of the Lenoir. There is also a gray to pink lime-sandstone ("marble") facies in several widely scattered localities. [J.R.]

Mount Merino member of Normanskill shale. *See* Austin Glen member.

Murfreesboro limestone. Determination of the true position of the Murfreesboro limestone in the Appalachian region (Cooper, 1945, p. 268–272) has revealed the erroneous nature of the traditional correlation of the Stones River of Central Tennessee with the lower or Chazy portion of the Champlainian succession of the southern Appalachian Valley. The Murfreesboro is more like the Black River than like any part of the Chazy. Indeed, it is not unlikely that the Murfreesboro occupies about the same stratigraphic position as the supposed Lowville limestone which occurs below the Chambersburg limestone of southern Pennsylvania. A possible age equivalence with the Pamelia limestone is suggested by mutual occurrences of *Tetradium syringoporoides*, *Leperditia fabulites*, *Ancistrorhycha costata*, and such genera as *Kionoceras*, *Phragmolites*, *Polylopia*, and *Lophospira*. [B.N.C.]

Mystic conglomerate. The age of this conglomerate is uncertain, but the diverse ages of some of its boulders are of interest. In general they are of Lower Ordovician age and range from approximately basal Ordovician *Leiostegium* zone to the equivalent of the Table Head and Upper Pogonip formation. *Kirkella curiosa* (Billings), a guide fossil to the high Canadian (Smithville-Black Rock), was first described from boulders of this conglomerate.

Although the Canadian boulders are of considerable interest the more abundant boulders of the higher and probably post-Canadian masses are important and significant. These boulders contain such fossils as the trilobite *Ectenonotus*, well known from the Table Head limestone of Newfoundland but less well known from the high Pogonip of Nevada. Many bizarre genera and species of brachiopods occur which are known elsewhere in Newfoundland and Nevada. Recently specimens have been seen from some of the boulder beds of Lévis which contain fossils suggesting those of the Mystic conglomerate. It is thus possible that the boulder beds containing these fossils are of approximately the same age as the Mystic conglomerate. [G.A.C.]

Narwhal Sound formation. The Narwhal Sound formation rests upon the Cape Weber formation (of youngest Canadian age) and contains *Bathyurellus*, which is not known above the Chazyan (Poulsen, 1937, p. 72). [C.O.D.]

Nelson River limestone. The Nelson River limestone contains a fauna some elements of which show Trenton affinities while others are Richmond species or genera. Among the Richmond genera are *Halysites* and *Plasmopora*, and the association indicates correlation with the Lower Richmondian, English Head formation, of Anticosti Island. Savage and Van Tuyl (1919) correlated it with the Red River formation of Manitoba and some part of the Galena of the Upper Mississippi Valley. It is here assigned to the Lower Richmondian. [W.H.T.]

New Richmond sandstone. New Richmond is a name proposed by Wooster (1882) for a sandstone ranging from 7 to 15 feet thick found in the bottom of three wells near the town of New Richmond in western Wisconsin. This sandstone has been assumed to lie between the Oneota and the Shakopee dolomites. At Burkhardt Dam on Willow River, a few miles below New Richmond, there are five thin beds of sandstone separated by dolomitic limestone through a thickness of 35 feet. Sardeson (1934) found fossils in the separating dolomites which he considered of Shakopee age. One of these sandstones may be the New Richmond, or perhaps the name should be applied to the entire zone in which the sandstones are present. At Lanesboro, Minnesota, the Prairie du Chien group contains a zone of sandstone 35 feet thick. It is not known that this sandstone is on the same stratigraphic level as the sandstones at New Richmond. There is 3–4 feet of sandstone in the top part of the quarry at Mankato, Minnesota. This separates excellently bedded dolomitic limestone below from irregularly bedded dolomitic limestone above. Except at or near the base, there is no sandstone in the excellent section of the Prairie du Chien group on the highway near Stockton, Minnesota, but the upper limestone, about 65 feet thick, is sharply distinguished by the great abundance of *Cryptozoön* and irregular bedding from the underlying evenly bedded limestones with few

Cryptozoön and a thickness of about 80 feet. There is no sandstone in the middle part of the section at Stillwater, Minnesota. There are two sandstones in the exposures of the Prairie du Chien group, near the town of that name in Wisconsin, of which the lower is 2.8 feet thick and the upper 1 foot thick. The facts seem to show, as Schwartz (1936) has pointed out, that there are locally several sandstones in the middle part of the Prairie du Chien group and that the name New Richmond probably was given to different units in different sections. In view of the uncertainty as to the exact significance of the name of New Richmond, Stauffer and Thiel (1941) proposed the name of Root River for the sandstone in the middle part of the Prairie du Chien group as it is developed in southeastern Minnesota and eastern Iowa. This has not improved the situation however, since it is not certain that the name is applied to the same sandstone in all places. If the Shakopee exists as a formation and is unconformable on the Oneota, as has been stated by some geologists, the sandstone or sandstones may mark the stratigraphic break and occur at several levels on and above the unconformity. On the other hand, the sandstones may be no more than the deposits of occasional great storms. Similar sandstones are not uncommon in the lower part of the Prairie du Chien group. A sandstone correlated with and named the New Richmond is in the middle part of the Prairie du Chien formation of Illinois. This sandstone has considerable thickness. [W.H.T.]

Normanskill shale. See Austin Glen shale member of Normanskill shale.

Nunatami formation. Teichert (1939, p. 111) cites graptolites and numerous other fossils indicative of Canadian age. According to Poulsen (1937, p. 68), beds carrying the Nunatami fauna are directly overlain by the Cape Weber fauna in Grinnell Land. [C.O.D.]

Oil Creek formation. This formation contains abundant specimens of the trilobite *Pliomerops barrandei*, which is also abundant in the high Pogonip of Nevada as seen in the Eureka District, the White Pine District, and the Toquima Range. It overlies the *Desmorthis* zone but contains some elements of the latter. [G.A.C.]

Oranda formation. This formation contains a modified and amplified lower Edinburg (*Echinosphaerites* zone) fauna. In the areas in which it has been studied by Cooper and Cooper it is mostly a somewhat calcareous silty fine-grained sandstone. When leached of its lime it becomes a punky sandy rock containing exquisite impressions of the contained fossils. Faunal links with the Lower Edinburg limestone are the abundant *Christiania*, *Orthambonites*, new genera of sowerbyelloids, *Oxoplecia*, and *Resserella*. Among the trilobites, *Cryptolithus* is present but rare. *Echinosphaerites* is so abundant that the Oranda fauna might be interpreted as a recurrence of the basal Edinburg fauna.

An interesting section occurs at Green Mount Church about 5 miles north of Harrisonburg, Virginia. Here the Oranda is more limy than in localities farther east, and brachipods are very abundant. Overlying the Oranda is a considerable thickness of blocky sandy shale abounding in *Cryptolithus* and with *Brongniartella* abundant not far above the base. This is the Salona assemblage which, as shown by its brachiopods, must have been derived from the Oranda fauna. [G.A.C.]

See also Chambersburg and Eggleston.

Orchard Creek shale. See discussion under Girardeau limestone.

Ottawa limestone. The Ottawa formation consists of approximately 700 feet of limestone with a few basal beds of shale and sandstone, and is a record of continuous deposition during Black River and Trenton time. Studies of many cross sections, well records, and surface outcrops show that subdivisions into members or other stratigraphic units made heretofore have been arbitrary. Variations in thickness of such units occur from place to place and are probably due to environmental conditions that permitted variable rates of accumulation of the sediments. This view is strengthened by a detailed study of the prolific fauna of the formation. Many species persist throughout the entire thickness of the limestone section; few have a limited stratigraphic range. Gradual interfingering changes in faunal association are, however, a noticeable feature of the formation, but these are not faunal zones because, with a few exceptions, no one species is limited in its range, nor are there stratigraphic units having a definite

boundary. The species of these faunal associations do not necessarily have the same range from place to place due to variations in the environmental conditions, but they do have stratigraphic value, in that they occur relatively in the same succession from place to place. This interpretation is in line with what is taking place in the sea today—the deposits of two bays in close proximity not uncommonly vary in character and thickness of sediments and in the organisms that dwell in and on these sediments. [A. E. W.]

Kay (1937; 1942) considers the Ottawa limestone to be separable into lithologic and time-stratigraphic formations and to contain regional unconformities. Studies by Chenoweth (1949), using statistical methods, have shown that there are consistent and significant lithic differences, but that they are not obvious. [M. K.]

Ottosee shale. Although Ulrich introduced the name Ottosee shale in 1911, the formation was not defined nor a type locality indicated until publication of the Lexicon of Geologic Names (Wilmarth, 1938). At the type locality in Chilhowie Park, Knoxville, Tennessee, the Ottosee is poorly exposed, and the upper boundary of the formation is a fault contact. The beds to which the name Ottosee has been applied are characteristically buff-colored and are very shaly, and at Knoxville most of the Ottosee seems to be of upper Benbolt and Wardell age. In median belts of Tennessee, near Fountain City, Luttrell, and Thorn Hill, a buff shaly limestone developed in the upper part of the Lincolnshire limestone has also been called Ottosee. The name Ottosee is a convenient designation for a facies of the Middle Ordovician that occurs primarily in the Benbolt-Wardell interval but also at lower horizons, and for that reason the name should not be regarded as having any precise time-stratigraphic significance. [B.C.]

The type Ottosee shale on strike with Column 38 is not equivalent to more than a small part of the type Sevier shale (*see* under heading Sevier), and the term is useful for the post-Holston pre-Bays shale unit of the Knoxville area (Cols. 36, 38), to which the name Sevier should not be restricted. The Ottosee contains lenses of "marble" (reef limestone and associated lime sandstone), but these can ordinarily be distinguished from the Holston "marble" (including the so-called Tellico sandstone) which is a persistent unit in the Knoxville area. In the thick shale sequence around Bays Mountain (Col. 35), the Holston cannot be recognized, and the Ottosee and Athens shales merge into the Sevier shale. It is suspected that the Ottosee includes equivalents of all beds from the Ward Cove to the Wardell of the Tazewell County, Virginia, section (Col. 31), and of the Pierce, Ridley, and possibly basal Lebanon limestones of the Central Tennessee section (Col. 43). A tentative alternate correlation chart for the Lower Middle Ordovician rocks of East Tennessee, based on these suspicions, is given in Figure 1. [J.R.]

Perryville limestone. The Perryville beds outcrop in two great areas in central Kentucky, of which one is in a region centering around Frankfort and Versailles and the other in the region of the southern Bluegrass country around Danville and Harrodsburg. The two are separated by an area where the "Cynthiana" has been regarded as in unconformable contact with the Benson limestone. It can now be shown that the Cornishville or uppermost division of the Perryville limestone of the southern Bluegrass country, with its "recurrent" upper Benson fauna (*Stromatocerium* zone), is, instead, the upper Benson. The thickened "Cynthiana" includes in its lower part the equivalent of the Brannon limestone and upper Lexington limestone. Lithology and fauna over much of the area are essentially that of the normal Cynthiana limestone. Much of the Perryville limestone is a fine-grained and dove-colored rock facies increasing in importance to the south. Instead of resting unconformably on the lower Benson limestone (McFarlan, 1938), the Perryville is now known to be Benson, and there is a conformable sequence up through the Benson and "Cynthiana" beds. However, the "Faulconer" and "Salvisa" which form the "Perryville" limestone of the Frankfort-Versailles area are post Woodburn and not the true Perryville. Other names must be assigned to these strata. [A. C. McF.]

Plattin limestone. This formation should be assigned to lower Trenton or highest Black River rather than to the Lowville where it has been traditionally placed. It contains some fossils such as *Camerella bella* Fenton which link it to the "Tyrone" of the Central Basin of

Tennessee. The fauna is really not well enough known yet to be certain of its age, but the report of *Rafinesquina* and *Ceraurus* like *C. pleurexanthemus* are indications of an age younger than the Lowville. [G.A.C.]

The formation is separable (E. R. Larson, 1950) into several formations or members; the upper are early Trentonian, and the lower are later Bolarian, about equivalent to the Lowville and Chaumont. [M.K.]

Pogonip limestone. The Pogonip limestone of western Utah and eastern Nevada has been divided into 12 lithic and faunal zones, beginning with the basal *Symphysurina-Nanorthis* zone and extending to probable lower Chazyan zones that are partially gradational eastward into quartz sandy beds (Hintze and Webb, 1950; Hintze, 1952). *See also* Eureka quartzite. [M.K.]

Prairie du Chien group. The Prairie du Chien group includes the Oneota dolomite, the New Richmond sandstone, and the Shakopee dolomitic limestone. Relations of the Oneota and the Shakopee are by no means clear. Trowbridge has stated that neither in the laboratory nor in the field has any character been found by which the limestones in the quarry (the type locality) at Shakopee, Minnesota, could be distinguished from rock elsewhere considered Oneota. Stauffer's studies and the unpublished notes of Twenhofel show that the limestones exposed in the quarry at Shakopee are underlain by 66 feet of dolomitic limestone below a sandstone. These are exposed on the slope to, and in, the bank of the Minnesota River. The strata exposed in this river slope certainly represent a lower division of the Prairie du Chien group. A similar relationship is exposed about 9 miles to the south at a place known as Merriam Junction. These lower strata are well and evenly bedded, whereas the strata exposed in the quarry have irregular bedding and contain an abundance of *Cryptozoön*, but the strata exposed in the quarry are absolutely identical in appearance to strata exposed elsewhere in the lower part of the formation which are identified as Oneota.

The strata of the Prairie du Chien group contain few fossils other than the algal structures known as *Cryptozoön.* The best fossils, with few exceptions, are those collected from chert piles along fence lines and sink holes to which the farmers hauled the chert from the cultivated fields. Fossils thus collected seem to have been assigned to parts of the formation in accordance with the personal psychology of the collectors. Because of the uncertainty of the name Shakopee, Kay (1935) revived the name of Willow River, originally proposed by Wooster (1882), for the upper limestones of the Prairie du Chien group. This has been no solution of the problem [W.H.T.]

Providence Island dolomite. See Bridport dolomite.

Ramshorn slate. The Ramshorn formation of Idaho (Ross, 1934) consists of 2000 feet of slate and quartzite above, and 500 feet of conglomerate at the base. Lower Deepkill fossils are present in parts of the formation and show its age to be Canadian. [W.H.T.]

Red River formation. The Red River formation of Manitoba has led to considerable difference of opinion insofar as correlation is concerned. As defined by Dowling (1900) the Ordovician rocks on the east side of Lake Winnipeg comprise, in ascending order, the Winnipeg sandstone, Lower Mottled limestone, Cat Head limestone, Upper Mottled limestone, and Stony Mountain formation. Foerste (1928) grouped these strata in three formations which in ascending order he defined as the Winnipeg, the Red River, and the Stony Mountain. It seems probable that the Winnipeg sandstone should be considered the initial deposits of the Red River formation as has been suggested by Savage and Van Tuyl (1919). Dowling assigned to the Trenton, the strata defined by Foerste as Red River, and his chart indicates that he considered the Winnipeg sandstone transitional from the Black River to the Trenton. Whiteaves (1897), although assigning the Red River formation to the Utica and Trenton, seems to have been the first to note that some of the fossils are "supposed to be restricted to the Hudson River group" [Richmond]. Bassler (1915) stated that the Red River cephalopods contain species derived from the Richmond and that these beds are of Richmond age. Foerste and Hussey (1928) also assigned the Red River formation to the Richmond. Foerste and Savage (1927), in describing the cephalopods from the Hudson Bay area, note that the Shammatawa and Stony Mountain formations are definitely of Richmond age and that the Winnipeg limestone [Red River] of southern Manitoba has no

equivalent on Anticosti. Foerste (1929) states that the Red River formation of Manitoba and similar formations elsewhere in the northern region are of Richmond age. He stated without reservations that "the Red River formation is regarded of later age than the Lowville, Decorah and Prosser, notwithstanding that its fauna appears to have wandered from the north, rather than from the south, at least in part" and "the lower Richmond age of the Red River fauna is accepted" (p. 37). He retained this opinion in 1933 (p. 63) and stated

> "The Red River formation and its equivalents is one of the most remarkable of known Paleozoic formations on account of its enormous extension in a north-south direction, its range from northwestern Greenland to south-central Oklahoma equaling more than thirty-one hundred miles and extending from the most northern fossiliferous areas known in the Arctic, to the southern part of the temperate zone. The most southern part of this Arctic invasion is in the El Paso area, in the extreme western part of Texas."

The fauna finds its closest correlative in the Anticosti section in the English Head formation. [W.H.T.]

Classification of the Red River, Cape Calhoun, Liskeard, Bighorn, Fremont, Whitewood, Maravillas, and similar formations as wholly Richmondian is questioned by Kay, though all seem essentially correlative (Miller, 1932; Miller and Furnish, 1937; Miller and Carrier, 1942). He believes they are wholly or principally Trentonian (Kay, 1935; Teichert, 1937). (1) The preponderant fauna of the Red River and Cape Calhoun is of forms known only in the Trenton and of indigenous fossils, whereas few forms are known in the Richmond and not in the Trenton; the number of the latter is decreasing (Flower, 1942; 1943). (2) The graptolites in the Maravillas and the subsurface Whitewood are of middle Trenton types (King, 1937; Decker, 1942); the conodonts of the Harding (basal Fremont) and basal Whitewood are like those in formations correlated with Black River and lower Trenton (Branson and Mehl, 1933; Furnish, Barragy, and Miller, 1936); the fauna of the lower Cape Calhoun has lower Trenton affinities (Teichert, 1937). (3) Classification of the formations as Richmondian introduces peculiar subsurface and paleogeographic relations: the Trentonian (Galena) limestones in the upper Mississippi Valley would become absent directly across the Sioux "uplift"; the Trentonian ("Kimmswick-Viola") of the North Kansas Basin, bevelled and thickening northward (Lee, 1943; Taylor, 1947), would similarly disappear; the Trentonian (Viola) of Oklahoma and Texas would pass in the subsurface into Maravillas and Montoya limestones classified as Richmondian; the "Arctic" faunas in the Stewartville and Viola would become isolated from the Arctic. (4) Classification of outcropping formations as Trentonian does not deny the probability of Richmond equivalents in the subsurface in the basins (Ehlers, 1943); Richmondian formations such as the Maquoketa and Stony Mountain (Okulitch, 1943) outcrop and are known to bevel the Trentonian in the subsurface (Lee, 1943; Taylor, 1947). [M. K.]

Richmond beds of Kentucky. Foerste (1912) recognized the Sunset as the lower member of the Arnheim formation and states:

> "The Sunset division is included in the Richmond only for the reason that southward, in Kentucky, it represents a period of diastrophic movement, the nearest thing to sandstone sedimentation found in this part of the Cincinnatian section, and is regarded as inaugurating a new period of sedimentation rather than closing a former period. It is quite in keeping with this view, that northward, where no similar diastrophic movements are recorded, there should be no evidence of a faunal break sufficient to demand the separation of the lower or Sunset division of the Auburn from the Mount Auburn member.
>
> "Evidence of the Maysville-Richmond boundary was summarized by Cumings in 1922 as follows: 'It may be that the dividing line between the Maysville and Richmond should be placed at the base of the Oregonia beds where the first *Batostoma varians* first appears. It should not be placed at the base of the Arnheim.' "

The Kentucky section supports this view.

The fossiliferous Richmond section of Ohio and northern Kentucky becomes progressively dolomitic and barren to the south along the eastern outcrop and the recognized divisions progressively less determinable. In the eastern and southeastern counties of the Bluegrass, only the Arnheim remains fossiliferous, and it and the underlying Tate-Mt. Auburn also exhibit dolomitization. In the subsurface to the east the dolomites become progressively shaly, and red beds make their appearance. [L. B. Freeman]

Ridley limestone. The brachiopods of the Ridley, soon to be described by G. A. Cooper,

are most like those of the high Black River of New York. The Pierce, underlying the Ridley in the Central Basin of Tennessee, contains *Fascifera*. In the Appalachians the Pierce species of *Fascifera* occurs in the Benbolt and Wardell. In the latter formation it and *Ancistrorhyncha*, another Ridley type, occur in abundance associated with *Tetradium* of the bundled Black River types. Indications are that Ridley-Pierce are of high Black River age even though they underlie *Cryptophragmus*-bearing Lebanon limestone. [G. A. C.]

Rockdell limestone. The name Rockdell limestone has been introduced (Cooper, 1948) as a formation name in areas where the Ward Cove and Peery limestones are not separately recognizable. The Ward Cove and Peery together undergo considerable facies variation. In Russell County, the Ward Cove-Perry succession is practically all calcarenite in the Elk Garden sector, nearly all dove-gray calcilutite near Swards Creek, but practically all cherty bluish-gray limestone southwest of The Parsonage, near the Russell Scott County line. As shown on the correlation chart, Kay has identified separate equivalents of the Ward Cove and Peery far away from the Tazewell County area of Virginia, but it seems very doubtful whether this is justifiable usage. The projection of these formation names over such wide areas implies correlations of a precise character for which, at present, there is only insufficient supporting evidence. [B. C.]

Romaine formation. The Romaine formation (Twenhofel, 1938) of the Mingan Islands on the north coast of the Gulf of St. Lawrence consists of dolomitic limestones that are unconformable with the overlying Mingan formation. Fossils are few and poorly preserved, and those present indicate a Canadian age. [W. H. T.]

St. George formation. The St. George formation, 2000 to 3000 feet thick, consists mostly of dolomite with some interbedded shale in the lower part and some interbeds of limestone. Its faunas indicate that much of the Canadian Series is represented. The middle part is characterized by *Lecanospira*, and the upper part by large species of piloceratids such as *Cassinoceras*, and by a large species of *Ceratopea*. [C. O. D.]

St. Luke limestone member. This unit was given member recognition (Cooper and Cooper, 1946, p. 78–83), by reason of its relative purity and possible economic value as a source of agricultural lime, in western belts of Shenandoah and Rockingham counties, Virginia. Through fossils, the St. Luke limestone is linked with the Wardell-Witten interval of the Clinch Valley district of southwestern Virginia. It is not to be confused with the Collierstown limestone which is correlated with the Oranda and Curdsville. At the south edge of Lexington, Rockbridge County, Virginia, a calcarenite at the top of the Edinburg is identified as the St. Luke member, but a few miles away at Collierstown, Rockbridge County, the St. Luke is supplanted by cobbly Edinburg beds, and the calcarenite which caps the Edinburg is the Collierstown limestone. [B. C.]

Kay believes the "St. Luke" limestone of the Lexington area, Virginia (Col. 27, Cooper and Cooper, 1946), to be Collierstown, and that tentatively identified in the Fort Loudon section, Pennsylvania (Cooper and Cooper, 1946), to be considerably older, equivalent to the Snyder limestone (Craig, 1941). [M. K.]

St. Paul's group. This group was named, but not adequately defined, by Helgi Johnson (1941, p. 143), who stated that it includes graptolite faunas of late Deepkill and early Normanskill age. Ruedemann (1947, p. 59–60) has listed graptolites collected by Johnson from the St. Paul's group and concludes that they include both Deepkill and Normanskill faunas. [C. O. D.]

Sarbach limestone. The Sarbach formation, consisting of limestones, contains, according to Kirk (1934), the *Taffia* [= *Hesperonomia*] fauna, is younger than the Mons, and correlates with the upper part of the El Paso limestone. Walcott (1928, p. 289) recorded *Phyllograptus* in the formation. [C. O. D.]

Saturday Mountain formation. The Saturday Mountain formation (Ross, 1934) consists of around 3000 feet of dark limestone which contains fossils diagnostic of the early Richmond invasion from the Arctic. [W. H. T.]

Schenectady flags. See Austin Glen member of Normanskill shale.

Sequatchie formation. The Sequatchie has long been considered the marine equivalent of the Juniata formation of Richmond age (Butts, 1932; 1933; 1940). In 1944, the writer found Maysville fossils which elsewhere occur just below the Juniata formation as developed at

Hagan, Lee County, Virginia. The same situation has just been discovered in a number of places along the northwest side of the Appalachian Valley in Tennessee—namely, that the Sequatchie includes Maysville as well as Juniata correlatives. [B. C.]

Sevier shale. The beds to which this name has been applied constitute a drab-buff shale-siltstone facies of the Middle Ordovician in eastern Tennessee. The type Sevier probably falls within the upper Benbolt-Witten interval of median belts of southwestern Virginia and Tennessee. In some places where no Tellico is recognizable, the Sevier may range downward to lower stratigraphic levels of the Benbolt. In many respects the typical Athens shale of the Calhoun-Athens district of Tennessee is of the same facies as the Sevier. [B. C.]

The term Sevier shale has been applied to Ordovician calcareous shales in East Tennessee and vicinity that range in age from Chazy to Maysville. The type area around Sevierville is largely of Athens age (pre-Holston, therefore pre-Lincolnshire?) but includes also a Holston equivalent (Sevier sandstone lentil of Keith, Loudon, and Knoxville folios) and beds of Ottosee age. If the term has any value, it is as a general term for the pre-Bays Middle Ordovician shale of the Bays Mountain synclinorium (Col. 35), where, in the absence of a clear equivalent of the Holston, the Athens and Ottosee cannot be readily separated (Fig. 1). [J. R.]

Shammattawa limestone. The Shammattawa formation on Hudson Bay contains many Richmond species or species of Richmond affinity together with some species of Trenton aspect. The formation belongs to the upper Richmond. [W. H. T.]

Shelburne limestone. According to Flower (1947), the upper part of division A (Clarendon Springs dolomite) as well as division B (Shelburne) are Gasconade. [M. K.]

Skoki limestone. The Skoki formation of British Columbia is composed of limestone which Walcott (1924; 1928) describes as overlying the Sarbach formation of Canadian age. It carries a fauna that is referred to the Chazyan. [W. H. T.]

Snooks Arm group. Named by Snelgrove (1931, p. 9), this group includes a complex of sedimentary beds, pyroclastics, and pillow lavas along the northwest side of Notre Dame Bay. Snelgrove reported that graptolites indicate the second and third zones of the Deepkill shale. [C. O. D.]

Spechts Ferry shale. This lower shale member of the Decorah formation has been correlated consistently with the Black River, but the presence of *Rafinesquina* and *Doleroides* suggests to Kay that it is lower Rocklandian, basal Trentonian. The Quimby's Mill member of the Platteville formation (Agnew and Heyl, 1946), the "glass rock," has been included in the Spechts Ferry (Kay, 1929), but is older. [M. K.]

Stones River group. The stratigraphic reassignment of the Stones River group to the Black River stage relieves a source of embarrassment in central Kentucky, as the High Bridge succession is conformable throughout. [A. C. McF. and E. R. C.]

Stony Mountain formation. There seems to be general agreement that the limestones which form the Stony Mountain formation of Manitoba are of Richmond age. The position is well up in the Richmond as indicated by the presence of such common forms as two species of *Beatricia, Rhynchotrema perlamellosa,* and others. The *R. perlamellosa* is much larger than any known elsewhere from the Richmond. The formation was subdivided into named members in 1943 by Okulitch who listed its faunas and confirmed its Richmondian age. [W. H. T.]

Swan Peak quartzite. The Swan Peak formation of northeastern Utah and southeastern Idaho consists of quartzite and carries a fauna (Richardson, 1913; Ross, 1949, p. 479) indicating correlation with the *Anomalorthis* zone of the Pogonip of Nevada. [G. A. C.]

Table Head formation. The Table Head formation consists mostly of light-gray limestone and bears a prolific fauna of gastropods, cephalopods, ostracods, etc. At the top it grades into interbedded black limestone and shale and finally into black shale. This uppermost member bears a distinctive graptolite fauna including *Phyllograptus, Tetragraptus, Diplograptus,* and *Climacograptus.* This is obviously a pre-Normanskill fauna, and, so long as the Normanskill was considered to be of Chazyan age, the graptolites seemed to indicate a pre-Chazyan age for the Table Head limestone, whereas the cephalopods, gastropods, brachiopods, and

trilobites indicated a post-Canadian age. But the Chazyan age of the Normanskill graptolites never rested on good evidence, and, now that G. A. Cooper and Byron Cooper have shown that in the Athens shale they are in beds of Black River age, no reason remains for placing the Table Head formation below the Chazyan. Evidence for Middle Ordovician rather than Canadian age may be seen in the presence of a common, large actinosiphonate nautiloid, *Cyrtonybyoceras*, and by the large species of *Maclurites* such as *M. speciosus* and *M. emmousi*, and by some of the brachiopods, notably *Aporthophyla*. Nevertheless there are few if any faunal identities with the type Chazyan, and if the Table Head formation is of the same age it belongs to a distinct faunal province. [C.O.D.]

G. A. Cooper has already remarked on the affinities of the Table Head brachiopods with those of the high Pogonip of Nevada. The Table Head facies is strikingly like that of the Whitesburg of Tennessee, and its contained trilobites have many similarities. Nevertheless, such genera as *Ectenonotus* indicate an age older than that of the Whitesburg. The brachiopods of the Table Head actually are of genera and types that are more like Canadian forms. The orthoid ones having a dalmanelloid form have proved to be like *Archaeorthis* or *Orthidiella*. *Orthidium* is abundant in places. The camerellids are referrable to *Idiostrophia* or are more like Canadian forms. Brachiopods like *Taffia* occur, and *Aporthophyla* is well known from the Table Head. This is thus an interesting example of facies development in which the faunas are parallelisms rather than identities in both the trilobites and the brachiopods. The graptolites of the Table Head have affinities with the Canadian but are still to be described in detail. [G. A. C.]

Tank Hill limestone. The Tank Hill formation of Nevada is composed of limestone (Westgate and Knopf, 1932) and probably is unconformable upon the underlying Yellow Hill limestone. The formation is referred to the Chazy on the basis of identified fossils (Kirk in Wilmarth, 1938). [W. H. T.]

Tellico formation. Probably less is known about the Tellico than about any other Champlainian formation in the southern Appalachian region. Except for several interbeds of rather resistant sandstone which make conspicuous knobs, the Tellico is very poorly exposed, and its faunal characteristics very poorly known. Fossils occurring in the lower 75 feet of the Tellico near Miser, Blount County, Tennessee, most nearly resemble those of the lower Benbolt beds of the Clinch Mountain belt. [B.C.]

Two different units in East Tennessee have been called Tellico sandstone. The Tellico of the type area (a few miles from Col. 37) is probably a sandstone tongue of pre-Holston, mid-Athens age. The so-called Tellico of the Knoxville-Athens area (Cols. 36, 38) is a quartzose phase of the Holston lime-sandstone and should not be separated from the Holston (*see* under heading Holston "marble," and chart, and Figure 1). [J. R.]

Tetagouche shale. The Tetagouche shale, named on the south side of Bay Chaleur, resembles the Mictaw strata lithologically and is similarly deformed. Graptolites cited by Young (1911, p. 31) indicate Normanskill faunal zones, but top and bottom limits are unknown. [C. O. D.]

Trenton limestone. The Trenton formations of New York and Ontario are classified by Kay as forming the type section of the Trentonian Series. [M. K.]

Tyrone limestone. The Tyrone limestone of Central Kentucky and parts of the Central Basin of Tennessee was regarded by Bassler (1932, p. 64–69) as Lowville in age. It is now believed to be Trenton because it succeeds the Lebanon and Camp Nelson limestones which are of late Black River (possibly Trenton) age and also because its bentonites place it stratigraphically above the Moccasin (late Black River or early Trenton) and below the Curdsville limestone. A Trenton age for the Tyrone is indicated in spite of the obvious fact that the Tyrone resembles the Lowville limestone in both facies and fossils. It must be emphasized that the faunas of all the Black River and lower Trenton calcilutites or "birdseye" limestones are remarkably similar by reason of the similar depositional environments and faunal ecologies of the several zones. The Tyrone fauna is an excellent example of a facies fauna and should not be given as much weight as stratigraphic position in determining its age.

The beds identified as Eggleston in the Ewing-Rose Hill district of Lee County, Virginia (Miller and Fuller, 1944), contain

Lebanon fossils and are therefore pre-Curdsville. They are older than the true Eggleston, and for this reason should be called Tyrone or Carters rather than Eggleston. [B. C.]

"Unnamed beds," Column 67. The upper 68 feet of bed previously embraced in the Deadwood sandstone was shown by Furnish, Barragy, and Miller (1936) to contain a fauna representing the upper part of the Platteville formation of the Upper Mississippi Valley. [W. H. T.]

"Upper Lenoir" limestone. The "Upper Lenoir" limestone is a loose designation for an as yet unnamed division younger than the true Lenoir which underlies it in the area of its most typical development near Friendsville, Tennessee. The "Upper Lenoir" is faunally linked with the Benbolt and with the lower part of the Edinburg formation. The post-Chazy or Black River age of both the Benbolt and lower Edinburg seems clearly indicated. It is important therefore to stress the lateral facies gradation of the *Christiania*-bearing "Upper Lenoir" into the typical Athens silty shale, because the latter has been said to be Chazyan, although no positive evidence was ever cited in support of the correlation. [B. C.]

Upper Utica shale. There is no general agreement as to whether the Utica shale (restricted) should be classified as uppermost Mohawkian or lowermost Cincinnatian. This refers to the Atwater Creek and Deer River shales of western New York and the Collingwood and Gloucester shales of Ontario, and their correlatives. These black shales were traditionally assigned to the Edenian until P. E. Raymond in a report of the Geological Survey of Canada (Summary Report for 1912, p. 342–350) included them in the Middle Ordovician. Although Raymond then treated them as the "Utica group", separate from and above the "Trenton group", Kay (1933, p. 2) followed his lead in shifting them to the Middle Ordovician but included them in the Trentonian Series. Since then, geologists in the United States have generally followed Kay, but Canadian geologists have continued to place them in the base of the Edenian. Kay feels that the choice is essentially an arbitrary one and holds no particular brief for the current usage south of the border. Since the difference in usage concerns classification rather than correlation it was decided that the matter could best be clarified by expressing uncertainty in the standard section at each end of the chart. [C. O. D.]

Vauréal formation. The Vauréal formation of Anticosti is typical Richmond, but species of Trenton aspect are present. Common Richmond fossils are two species of *Beatricia*, *Halysites*, *Paleofavosites*, *Lyellia*, *Sceptropora facula*, *Rhynchotrema perlamellosa*, and others. [W. H. T.]

Ward Cove limestone. Very little is known of the fauna of the Ward Cove limestone. A few of its fossils, including *Calliops strasburgensis*, *Ampyx americanus*, *Echinosphaerites*, *Nidulites pyriformis*, and *Sowerbyella negritus*, occur in the Liberty Hall black limestones and shales of the belt of outcrop along the northwest base of Walker Mountain in southwestern Virginia. The Rockdell limestone is recognized in areas wherein the Ward Cove and the succeeding Peery limestones cannot be separately distinguished. [B. C.]

Wardell limestone. Originally it was thought that the Wardell limestone was younger than the Gratton limestone (Cooper and Prouty, 1934, p. 872–875), but more recent work indicates that the Wardell grades laterally into the Gratton without any obvious intertonguing of the lithologies characterizing the two formations. Near Snowflake, Scott County, Virginia, a great limestone bioherm in the upper Wardell contains dove-colored limestone layers with Gratton fossils. [B. C.]

Western Brook Pond group. This group was named, but inadequately described, by Johnson (1941, p. 143), who reported graptolites of the middle Deepkill shale fauna. *See* discussion of Green Point shale. [C. O. D.]

Whistle Creek limestone. Considerable difficulty has been experienced in recognizing equivalents of both the Whistle Creek and Lincolnshire limestones in parts of the Shenandoah Valley of Virginia. The Whistle Creek appears to be well represented below the so-called Lowville limestone of Ulrich and Stose near Marion, Pennsylvania, but the Lincolnshire is not typically represented there. The so-called Lowville may be a dove-colored limestone facies of the Lincolnshire.

The faunas of the Whistle Creek and Lincolnshire limestones are similar, but resemblances with faunas of the Chazy are noteworthy only

in the Whistle Creek or in the local reefy calcarenites intercalated in the Lincolnshire limestone. One of the most important problems awaiting further work is the establishment of closer connections between the typical Lenoir of Tennessee and equivalent formations farther west in the median belts of the Appalachian region. [B. C.]

Whitehead formation. Cooper and Kindle (1936, p. 348) have shown that the Whitehead fauna is late Ordovician but with distinctly European rather than American affinities. Correlation with the Richmondian is therefore not precise. [C. O. D.]

Whitesburg limestone. The beds which Ulrich named the Whitesburg limestone near Bulls Gap, Hawkins County, Tennessee, comprise several hundred feet of black cobbly to platy limestones, including the *Nemagraptus gracilis* graptolite zone. The type Whitesburg therefore includes much more than Butts (1940, p. 154–156) included in the formation farther north in Virginia. The Whitesburg, as Ulrich defined it, is essentially synonymous with Liberty Hall limestone, a prior name which Butts and Ulrich rejected on the mistaken premise that it was synonymous with the Athens.

The relatively thin limestone zone at the base of the Liberty Hall, which Butts referred to as Whitesburg, has been renamed the Effna limestone in southwestern Virginia (Cooper, 1944, p. 59–65) and the Botetourt limestone member of the Edinburg formation in the Shenandoah Valley. [B. C.]

Whitewood dolomite. The Whitewood formation of the Black Hills is composed of dolomite deposited in the Arctic waters that invaded northern and Arctic North America in early Richmond time (Furnish, Barragy, and Miller, 1936). [W. H. T.] *See* Red River formation.

Witten limestone. Kay (1947) believes there is a disconformity within the *Camarocladia* zone of the type Witten limestone (Cooper and Prouty, 1943), the upper 20 feet being lower Trentonian, and the lower 45 feet being Bolarian, equivalent to part of the Stover limestone of central Pennsylvania; the section does not have beds corresponding to the Curtin limestone. [M. K.]

In the Hagan section (Column 34) Miller and Brosgé (1950) introduced the names Woodway limestone and Hurricane Bridge limestone, drawing the boundary between them at the base of a prominent zone of *Stromatocerium rugosum*. As thus defined the Woodway limestone includes the Witten limestone and some lithologically and faunally unrelated beds beneath the base of the Witten. These lower beds are actually linked both faunally and lithologically with the Hurricane Bridge limestone rather than with the Witten. It is proposed therefore to recognize the Witten limestone in this section and to reject the name Woodway. This will then leave a thin unnamed interval below the Witten. It may be desirable to redefine the underlying Hurricane Bridge limestone to include these unnamed beds. [B.C.]

Wonah quartzite. The Wonah formation of British Columbia is composed of quartzite (Walcott, 1924; 1928) and is not known to contain fossils. As it lies above the Skoki of Chazy age and below the Beaverfoot limestone of early Richmond age, its position is obviously somewhere in the middle Ordovician. [W. H. T.]

Woodway limestone. See Witten limestone.

Yellow Hill limestone. The Yellow Hill formation of the Pioche District of Nevada consists of limestone (Westgate and Knopf, 1932), carries the *Taffia* fauna (Kirk, 1932), and correlates with the upper part of the El Paso limestone. [W. H. T.]

Youngman formation. G. A. Cooper would place the Youngman formation in the lower Black River (Bolarian) for its lower member contains a species of *Christiania* similar to that in the *Christiania* zone ("Upper Lenoir") of eastern Tennessee (Columns 35–37). The Youngman conformably overlies the Carman quartzite, which Kay correlates with the lower Day Point, and the basal Youngman has faunal similarities to the upper Day Point when of similar lithology; Kay believes the Youngman to be Chazyan, equivalent to the upper Day Point, Crown Point, and Valcour formations of New York but of different lithofacies (Kay and Cady, 1947). [M. K.]

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Bibliographic references → 227a | 202 | 111, 200 | 131, 172a, 173, 212 | 131, 172, 174, 212, 215a | 217, 218 | 240 | 51, 55, 161, 238 | 37a, 37b | 250 | 86, 88, 98, 165, 43a, 85a

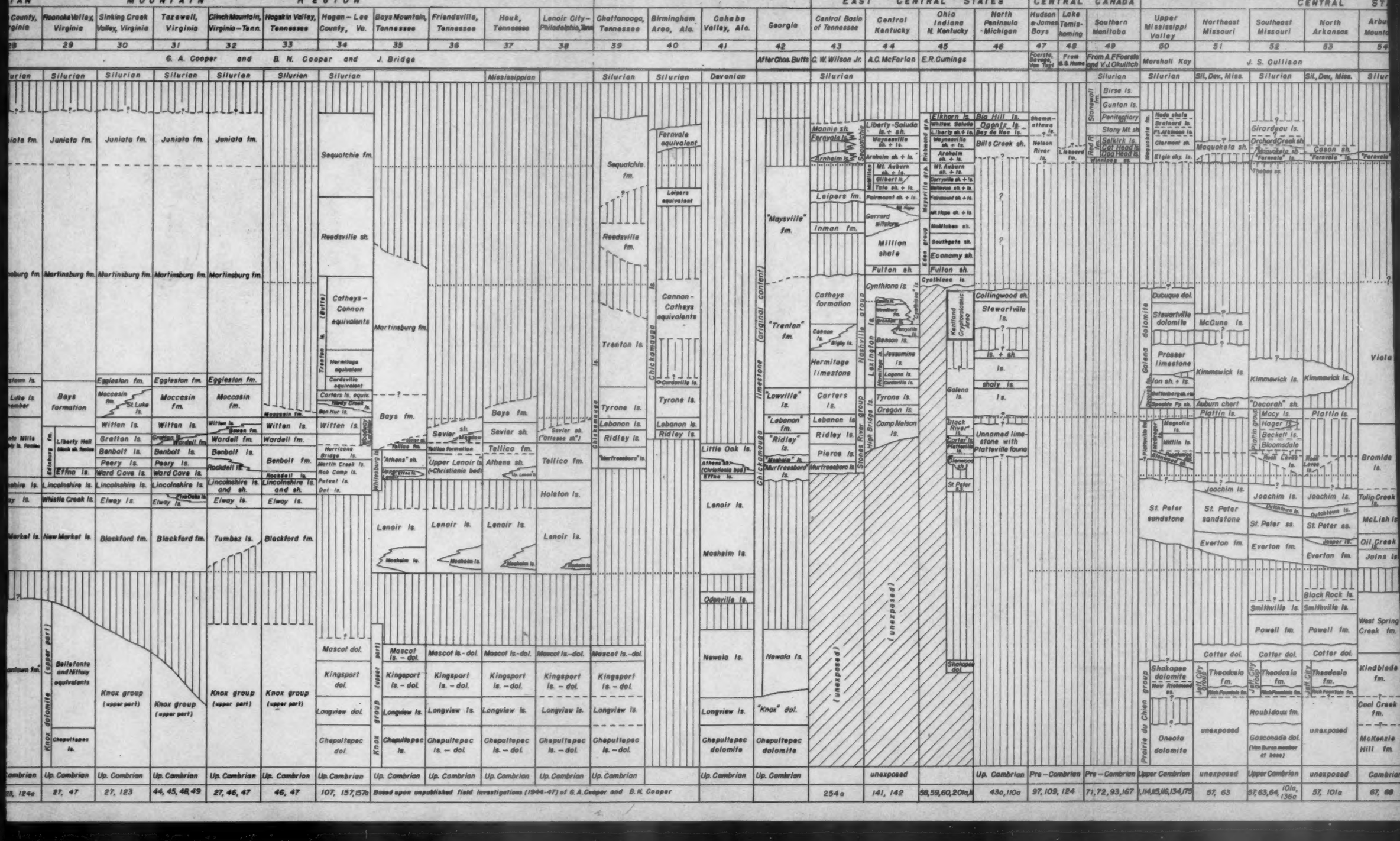
Chart 2. - CORRELATION OF THE ORDOVICIAN FORMATIONS OF NORTH AMER

By the Ordovician Subcommittee, W. H. Twenhofel, *Chairman*, Josiah Bridge, Preston E. Cloud, Jr., Byron N. Cooper, G. Arthur Cooper, E. R. Cum
James S. Cullison, Carl O. Dunbar, Marshall Kay, A. C. McFarlan, John Rodgers, H. B. Whittington, Alice E. Wilson, and Charles W. Wilson, Jr

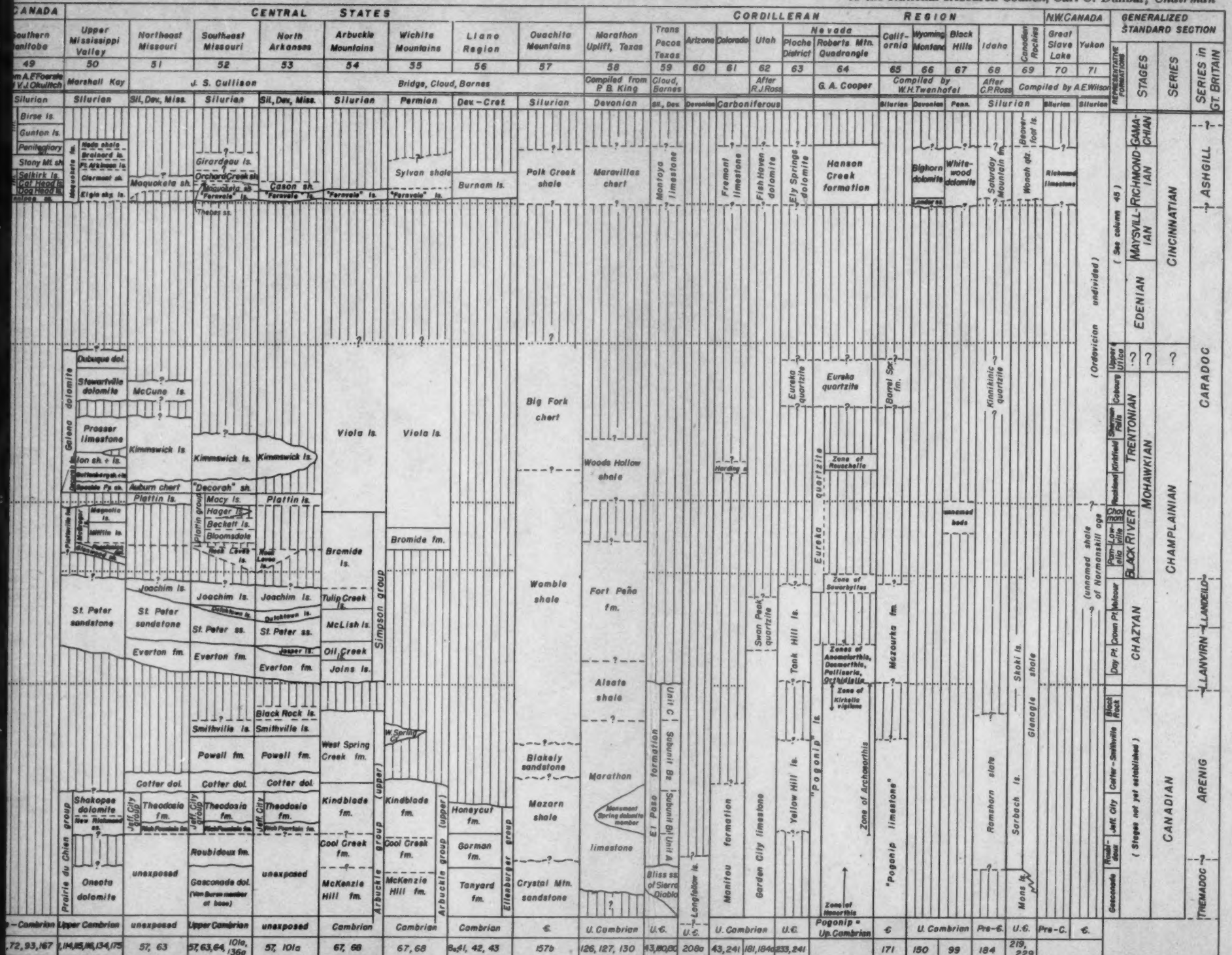
ITIME	CANADA			ONTARIO			VERMONT AND NEW YORK						APPALACHIAN MOUNTAIN REGION												
	Nova Scotia	Gaspé and New Brunswick	Quebec	Montreal Lowland	Ottawa—St. Lawrence Lowland	Central and Southwestern Ontario	Manitoulin and other islands	Taconic Area	Lake Champlain and Western Vermont	Northwestern Vermont Southeastern Quebec		Mohawk Valley	Northwestern New York	E. Pennsylvania N. New Jersey	Central Pennsylvania	Highland Co., Va — Monroe Co., W. Va.	Southern Penn. and Maryland	Luray District, Virginia	Strasburg Area, Virginia	Harrisonburg, Virginia	Lexington Area, Virginia	Bath County, Virginia	Roanoke Valley, Virginia	Sinking Creek Valley, Virginia	Tazewell, Virginia	Clinch Mountain, Virginia—Tenn.	Hogskin Valley, Tennessee	Hogan— County, Va
	7	8	9a	9b	10	11–12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	M.Y. Williams W.A. Bell	H.W. McGerrigle and F.J. Alcock	Compiled by Alice E. Wilson and B.A. Liberty					Marshall Kay																	G. A. Cooper and B. N. Cooper and			
	Sil., Dev., Carb.		Devonian, Pleis.		Pleistocene	Sil.+Pleistocene	Silurian	Pleistocene		Pilipaburg Seq.	Highgate Springs and Providence Seqs.	Silurian				Silurian	Silurian	Silurian		Silurian	Silurian	Silurian	Silurian	Silurian	Silurian	Silurian	Silurian	Silurian
		Whitehead fm. (Taboo) / Matapedia group	Richmond	Bacancour River sh. / Pontgravé River sh.	Queenston red shale	Queenston red shale	Kagawong ls.						Queenston red shale (truncated)		Juniata ss.	Juniata ss.	Juniata fm.		Juniata fm.	Juniata fm.	Juniata fm.	Juniata fm.	Juniata fm.	Juniata fm.	Juniata fm.	Juniata fm.			Sequatchie f
					Russell dol.	Meaford sh.	Meaford ls.						Oswego ss.	Shawangunk cgl.	Bald Eagle ss.	"Oswego" ss.	Juniata fm.			Oswego ss.									
			Lorraine group	Nicolet River sh.	Carlsbad sh.	Dundas sh. and ls.	Wekwemikongsing sh.			Note: Separated from Rosenberg Sequence on East and from Highgate Springs on West by thrust faults			Pulaski sh.	Shochary ss.	Roadsville sh.													Roadsville sh
				Leclercville sh.									Whetstone Gulf sh.																
			Utica gr.	Lachine bl. sh.	Billings sh.	Billings sh. / Blue Mt. sh. / Gloucester bl. sh. / Collingwood bl. sh.	Sheguindah sh. / Collingwood sh.			Philipsburg Seq.			Martinsburg shale		Martinsburg fm.	Martinsburg fm.	Martinsburg fm.	Martinsburg fm.	Martinsburg fm.	Martinsburg fm. (includes Salona equivalent)	Martinsburg fm.	Martinsburg fm.	Martinsburg fm.	Martinsburg fm.	Martinsburg fm.	Martinsburg fm.	Martinsburg fm.			
				Eastview ls.sh.									Holland Patent sh.		Antes sh.														
				Terrebonne bl. sh.+ls.									Leyden Creek sh.																
				Tetreauville bl. sh.+ls.	Cobourg beds	Cobourg ls.	Cobourg ls.						Dean River sh.		Coburn ls.														
				Rosemount ls.									Newsdogo sh.																
				St. Michel ls.	Sherman Fall beds	Sherman Fall ls.	Sherman Fall ls.						Cobourg ls.		Salona ls.	Salona ls.													
			Quebec City group	Mile End ls.	Hull beds	Rockland–Hull ls.	Cloche Island ls.						Dennark ls.		Rodman ls.														
				?Rockland ls.	Rockland beds								Sherman Fall ls.		Center Hall ls.														
				Leray ls.	Leray beds								Glens Falls ls.		Oak Hall ls.														
				Lowville ls.	Lowville beds								Isle la Motte ls.		Curtin ls.														
				Pamelia ls.	Pamelia beds								Rockland ls.		Stover ls.														
													Lowville ls.		Snyder ls.														
													Pamelia ls.		Benbolt ls.														
															Hostler ls.														
															Grazier ls.														
															Eyer ls.														
															Rockdale ls.														
															Glover ls.														
															"Tiger stripe" beds														
															Loysburg ls.														
															Blackford fm.														

IAN FORMATIONS OF NORTH AMERICA

Preston E. Cloud, Jr., Byron N. Cooper, G. Arthur Cooper, E. R. Cumings,
dgers, H. B. Whittington, Alice E. Wilson, and Charles W. Wilson, Jr.



Prepared under the auspices of the Committee on Stratigraphy of the National Research Council, Carl O. Dunbar, *Chairman*



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GEOPHYSICAL INVESTIGATIONS IN THE EMERGED AND SUBMERGED ATLANTIC COASTAL PLAIN

PART VIII. GRAND BANKS AND ADJACENT SHELVES

By Frank Press and Walter Beckmann

Abstract

A reconnaissance refraction survey was conducted on the Grand Banks, St. Pierre Banks, Cabot Strait Trough, and Banquereau. Three stations on the Grand Banks indicate sedimentary layers ranging from 2300 to 10,700 feet in thickness. The sediments are underlain by basement rocks having velocities of 16,150–18,200 ft/sec.

A striking feature, existing on a profile running from St. Pierre Bank across Cabot Strait Trough to Banquereau, is the occurrence under the trough of a prism of sediments that thickens to almost 14,000 feet near the northeast margin where it is almost entirely truncated by basement rock.

The sequence of subsurface layers found on the banks south and southeast of Newfoundland is not unlike that reported for the submerged shelf off the northeast coast of the United States and the banks off Nova Scotia. The seismic results and the recent results from dredging and coring operations support the hypothesis that the shelf off eastern North America is a depositional feature dating back to at least Lower Cretaceous time. The physiographic differences north and south of Cape Cod are believed to be due to erosion. The data suggest a structural origin for the Cabot Strait Trough, although the possibility of subsequent modification by glaciation is not ruled out.

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Introduction

In the summer of 1951 a series of seismic-refraction measurements was made in the North Atlantic Ocean on R. V. Atlantis Cruise 173, and R. V. Caryn Cruise 25 of the Woods Hole Oceanographic Institution, as a continuation of the Columbia University program of geophysical investigations of the sea floor.

In this paper we report on seven shallow-water refraction stations, made during the first 2 weeks of September, to ascertain the subsurface structure of the Grand Banks off Newfoundland, St. Pierre Bank, Banquereau, and the Cabot Strait Trough which extends from the Gulf of St. Lawrence. The results reported are necessarily of a reconnaissance nature since the program was planned to

determine only the major features of this large area.

The general geographic locations of the stations are shown in Figure 1. The more detailed navigation plots, showing shot and receiving positions, are shown in Figures 2. Positions at sea were obtained by Loran, star fixes, sun lines, and dead reckoning by both ships, and a running plot of the track was kept. At the beginning and end of each station a Loran fix was made; the relative positions of the ships were checked by Radar from the ATLANTIS whenever weather conditions were poor.

Unfavorable wind and current conditions sometimes caused a large amount of drift of the two vessels during the course of a station. This drift had only a minor effect on the results as shown by the matching of the travel-time reverse points at each end of a station.

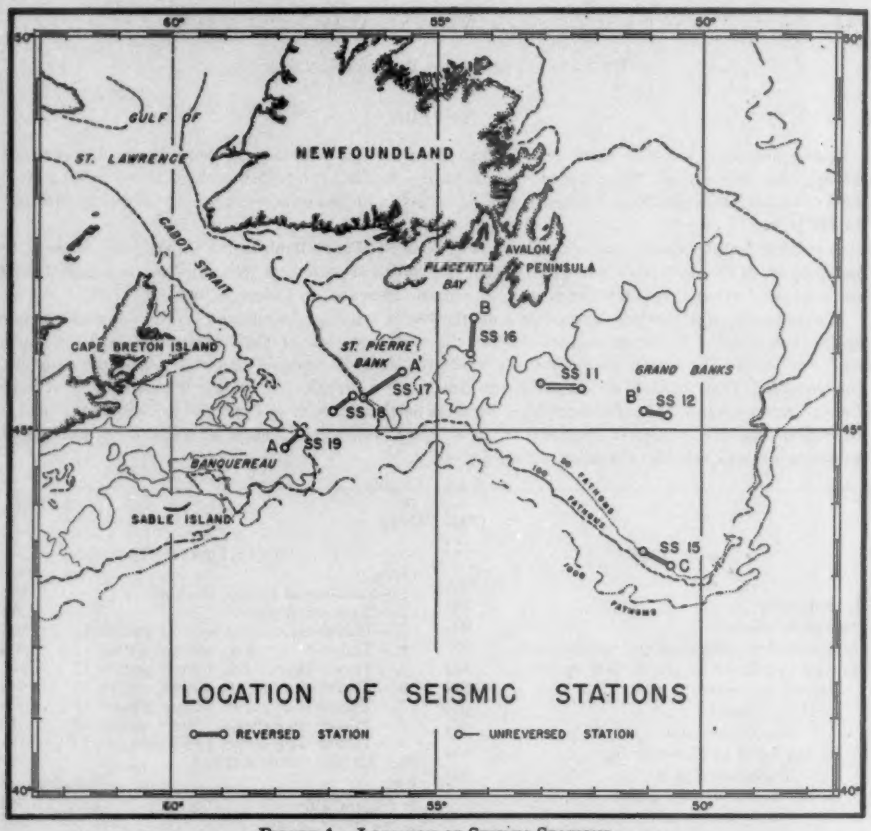


FIGURE 1.—LOCATION OF SEISMIC STATIONS
The letters B-B'-C, A-A', refer to the locations of the summary cross sections shown in Figure 10.

More precise investigations would require anchoring of the receiving boat and better methods for locating the position of the shooting boat.

ACKNOWLEDGMENTS

This survey was conducted by the Lamont Geological Observatory of Columbia University under contract NObsr 43355 with the Bureau of Ships and contract N6-onr-27113 with the Office of Naval Research. The explosives used

were furnished by the Bureau of Ordnance of the U. S. Navy.

The writers wish to thank the officers and crews of the Research Vessels ATLANTIS and CARYN of the Woods Hole Oceanographic Institution for their valuable assistance. The field work was possible only through the generous help of the following: Charles L. Drake, Maurice Major, John Northrup, Charles Bentley, Dave Warren, James Dorman, Leonard Johnson, Patrick Coyle, and Duncan Foster, Jr.

METHODS OF INVESTIGATION AND INTERPRETATION

The deep-sea instrumentation, shooting procedure, and hydrophone-handling techniques described by Officer *et al.* (1952, p. 780–783) were used successfully in shallow water. Very often the sinking time of the larger shots was sufficiently long to produce detonation on bottom.

The methods of interpretation used are those described by Ewing *et al.* (1939, p. 262–267) for reverse-profile shooting. It is worthwhile to repeat the assumptions underlying these methods: (1) Each layer is bounded at top and bottom by planes, and transmits seismic waves with a constant velocity. (2) At an interface between two layers, the path of a wave is determined by Snell's law. (3) A wave traveling in any layer with velocity V, and incident on the surface of the layer at an angle α with the normal, has an apparent velocity $V/\sin\alpha$ along the surface. (4) Any travel time is unchanged if shot point and recording position are interchanged.

The basic measurement in the refraction method is the variation of travel time of seismic waves with distance along a profile. The travel-time data are plotted in the form of time-distance curves as in Figures 3–9. If the above assumptions are satisfied, the travel-time curves are straight lines, and for horizontal layers the reciprocal of the slope of these lines gives the velocity of seismic waves in the refracting layer. From these velocities and the intercepts of the travel-time curves, depths to the refracting layers can be computed. For dipping layers the slope of the travel-time curve does not represent the true velocity but represents an apparent velocity which depends also on the dip. In this case a reversed profile consisting of measurements up and down dip is necessary to determine true velocities and layer depths. Travel-time curves for reversed profiles are shown in Figures 3–9. From assumption (4) it follows that for the up- and down-dip travel-time curves of a layer the reverse points are equal.

Travel-time data for a given layer are seldom available over the length of a profile. One reason for this is that refraction impulses can be identified with absolute certainty on seismograms only when they occur as first arrivals. Instrumental difficulties and misfires may cause the loss of data. In reconnaissance work refractions from a layer may be missed because of the large spacing of shots. Control over the slopes of travel-time curves, therefore, at best usually extends only over brief segments of a profile. A straight-line extension of the travel-time curve beyond the region of control is permissible if the initial assumptions are satisfied and if the ships do not drift off the profile. It is evident that matching of reverse points obtained by extension of travel-time segments indicates both the validity of the assumptions and negligible drift of the ships.

Often when refraction data for a layer are absent or are available only for one side of a reversed profile, approximate interpretations can be made which are sufficiently accurate for reconnaissance purposes. On one profile no refractions were obtained from the surface mud layer, yet its presence was inferred from the discrepancy between water depth as given by the echo sounder and the depth to the first layer computed from the refraction data. An acceptable approximation could be made, however, by assuming a travel-time curve with a slope giving a typical mud velocity and an intercept appropriate for the water depth. When data are insufficient for a reversed profile, either a zero dip is assumed, or a true velocity typical for the layer is applied. That this approximation is acceptable for reconnaissance work in this area can be seen by noting that, for reversed profiles, apparent velocities in Table 1 differ from the corresponding true velocities in Table 2 by less than 10 per cent.

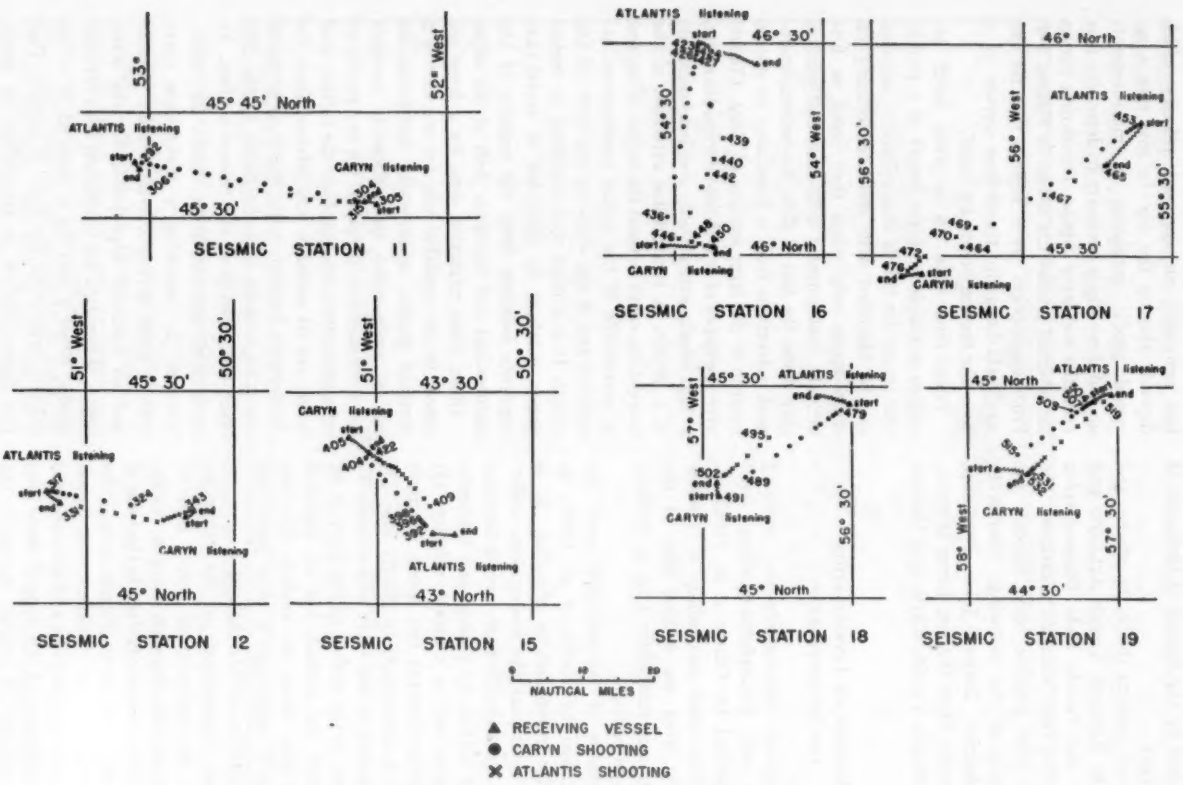


FIGURE 2.—NAVIGATION PLOTS

These show in detail the shot and receiving positions for each station. The receiving boat drift is indicated by a waved line between the start and end positions.

Travel-Time Data and Geophysical Results

General Statement

The travel-time curves are plotted in Figures 3–9. Sample seismograms are shown in Plates 1 and 2. Table 1 lists observed velocities and time intercepts for all stations. Table 2 lists true velocities, slopes, and thicknesses of layers. Beneath each travel-time curve is a geologic cross section derived from the data.

A. Grand Banks

Station 11 (*Fig. 3*).—This station consists of two lines of shots with receiving points separated by a distance of 32.5 nautical miles. Caryn data were obtained only for the first and second layers, due to instrumental difficulties. Four layers are observed on the Atlantis end. The mud layer was determined by assuming the velocity 5850 ft/sec obtained with more data from the Caryn end, and by using the single point from shot 292. As an intercept appropriate for the water depth is obtained this procedure appears to be justified. Similarly the 12,100 ft/sec layer is drawn on the basis of the Caryn reverse point and shot 293. The remaining layers are fairly well determined. In the absence of Caryn data for the deeper layers, only an approximate indication of the structure is obtained by assuming zero slopes. Velocities thus obtained compare favorably with observations at the reversed stations.

Station 12 (*Fig. 4*).—This is a reversed station indicating the presence of four layers. The 11,100 ft/sec layer found on the Caryn end is either masked or absent on the Atlantis end. High noise level due to heavy seas limited data on the deepest layer to a single point.

The cross section was computed assuming that the 11,100 ft/sec layer is masked at the Atlantis end and has zero slope, and that the deepest layer has a true velocity of 20,000 ft/sec and zero slope. The matching of the reverse points and the small computed slopes would indicate that the observed drift has a negligible effect.

Station 15 (*Fig. 5*). Five layers are indicated in this reversed station. The 6350 ft/sec layer is determined entirely on the basis of strong second arrivals. (*See*, for example, Plate 1, bottom record, event G_2.) The 13,350 ft/sec layer, well determined on the Atlantis side, is assumed to be masked on the Caryn side, the apparent velocity being determined by the reverse point, and the lowest velocity limit set by shot 418. The deepest layer is well determined on the Atlantis end and is drawn through the reverse point on the Caryn line, assuming zero slope. Here again drift effect is negligible for the precision required.

B. Approach to Placentia Bay

Station 16 (*Fig. 6*).—At this reversed station the first layer is determined on the basis of good second arrivals. The two intermediate layers are well determined. Shot 436 and shot 434 (the latter being shared with another line) are the only data available to determine the deep layer on the Atlantis line. On the Caryn line only the reverse point and shot 440 (also shared with another line) are available. Despite this poor determination the velocity of 20,950 ft/sec is not unreasonable.

An order of magnitude calculation indicates that the drift shown in Figure 2 can affect the velocity of the 18,200 ft/sec layer by about 3 per cent. If the 20,950 ft/sec layer has a slope of 3° or more, shot 436 would be seriously affected by the drift, and the determination of velocity and depth of this layer would be impossible with the limited data. The matching of the reverse points and the almost identical apparent velocities indicate negligible error in the determination of the 14,250 ft/sec and the 5200 ft/sec layers, despite the very large azimuth differences of the shot lines.

C. St. Pierre Bank, St. Lawrence Trough and Banquereau

Station 17 (*Fig. 7*).—At this station there is evidence of five layers. The first layer is fairly well determined from first and second arrivals on the Atlantis end and is fixed at the Caryn end by shot 476 and the reverse point. The 9300 ft/sec layer, well determined at the Caryn end, is almost masked on the Atlantis line. The 13,500 ft/sec layer is fixed by shots 455, 456, and 457 for the Atlantis

TABLE 1.—OBSERVED VELOCITIES AND TIME INTERCEPTS

Stations	V_1	V_{1a}	V_{1b}	V_{2a}	V_{2b}	V_{4a}	V_{4b}	V_{5a}	V_{5b}	V_{6a}	V_{6b}	T_{1a}	T_{1b}	T_{2a}	T_{2b}	T_{4a}	T_{4b}	T_{5a}	T_{5b}	T_{6a}	T_{6b}
11*	4875	5850	5850	12100	12100	17000	.....	19050	.....	.....	.....	.066	.066	.82	.82	1.21	....	1.81	....	....	....
12	4875	5750	5750	(11100)	11100	15750	16550	(19700)†	(20400)†	.....	.....	.052	.052	.56	.56	.70	1.00	1.60	1.78	.....	.....
15	4875	5800	5800	6350	6350	13650	13450	16600	18100	(20050)	21050	.06	.06	.25	.25	1.24	1.35	1.42	2.0	2.27	2.47
16	4875	5200	5200	14050	14450	17650	18700	20150	21850	.....	.....	.05	.05	.17	.52	.44	1.10	1.10	1.72	.....	....
17	4875	5700	5700	9350	9250	13800	13250	17750	16950	22100	(21100)	.04	.04	.57	.45	1.43	.75	1.81	1.20	3.23	2.60
18	4875	(5750)†	(5750)†	9850	9400	12700	12200	19500	20500	.....	.....	.276	.276	.85	.60	1.60	.87	2.42	2.75	.....	.....
19	4875	5800	5800	10400	10300	15000	15200	.....	.....	.....	.....	.029	.029	.81	.77	1.67	1.72	....	....	....	....

* Unreversed stations.

† Assumed velocity.

( ) Zero slope assumed for layer.

V_1 is water velocity in ft/sec; V_{na} and V_{nb} refer to the apparent velocity of nth layer, as seen from the "a" or "b" end of a station respectively, while T_{na} and T_{nb} are the corresponding time intercepts in seconds. The subscript "a" refers to the west end of a profile except for station 16 where it refers to the north end

TABLE 2.—TRUE VELOCITIES, SLOPES, AND THICKNESSES OF LAYERS

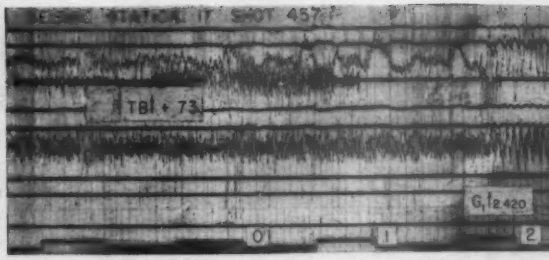
Stations	V_1	V_2	V_3	V_4	V_5	V_6	ω_{12}	ω_{23}	ω_{34}	ω_{45}	ω_{56}	h_{1a}	h_{1b}	h_{2a}	h_{2b}	h_{3a}	h_{3b}	h_{4a}	h_{4b}	h_{5a}	h_{5b}
11*	4875	5850	12100	(17000)	(19050)	.....	0	0	0	0	.....	290	290	2370	2370	2890	....	9960	.....	.....	.....
12	4875	5750	(11100)	16150	(20000)†	.....	0	0	−1.35	+1.32	.....	240	240	1590	1590	700	3000	11860	9620	.....	.....
15	4875	5800	6350	13550	17250	(20500)	0	0	+.21	−3.86	+3.64	270	270	1300	1300	2630	3020	1330	6410	12820	5070
16	4875	5200	14250	18200	20950	.....	0	−.31	−.83	−.35	.....	340	340	110	1090	3040	6470	11150	9360	.....	.....
17	4875	5700	9300	13500	17350	(21600)	0	+.23	+.60	−.40	−.43	190	190	1820	1380	5000	1520	2440	4210	18860	18920
18	4875	(5750)†	9600	12450	19950	.....	0	+.97	−.78	−2.56	.....	1270	1270	1440	540	5110	1690	4010	13950	.....	.....
19	4875	5800	10350	15100	.....	.....	0	+.18	−.75	.....	.....	130	130	2670	2530	5450	6120	.....	.....	.....	.....

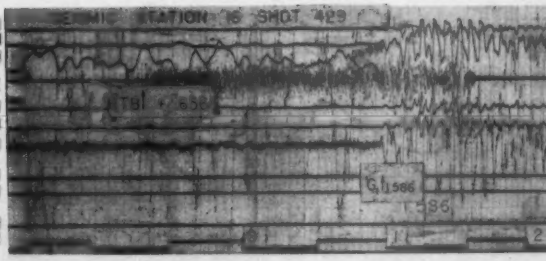
* Unreversed station.

† Assumed velocity.

( ) Zero slope assumed for layer.

Where V_n is the true velocity of layer "n" (subscript "1" referring to water) in ft/sec., $\omega_{n(n+1)}$ refers to the angle in degrees made by the n, n + 1 interface to the n − 1, n interface, while h_{na} and h_{nb} denote the respective thickness in feet of the nth layer at the a and b ends of the station. Positive values of ω indicate up dip of interface relative to preceding interface in direction "b" to "a".


LOW FREQUENCY LOW GAIN
MEDIUM GAIN
HIGH GAIN
RADIO - TIME BREAK
MEDIUM FREQUENCY LOW GAIN
MEDIUM GAIN
HIGH GAIN
HIGH FREQUENCY LOW GAIN
MEDIUM GAIN
HIGH GAIN
CHRONOMETER
TBI + 73
0
1
2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MEDIUM GAIN
HIGH GAIN
CHRONOMETER
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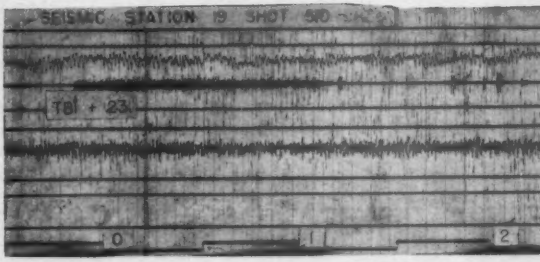
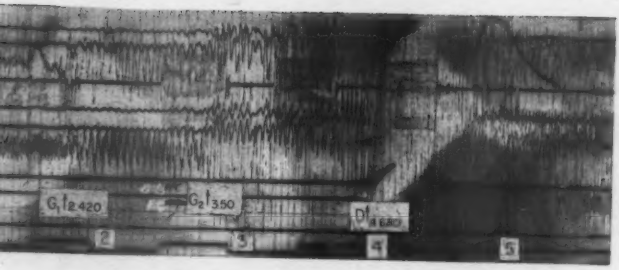
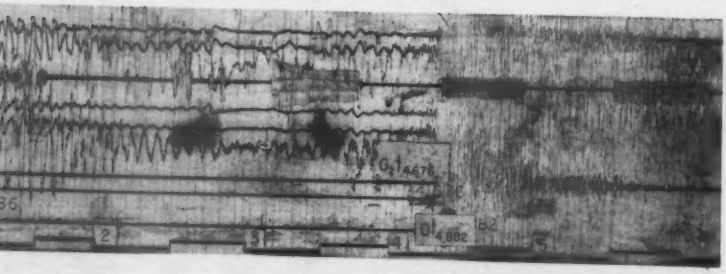
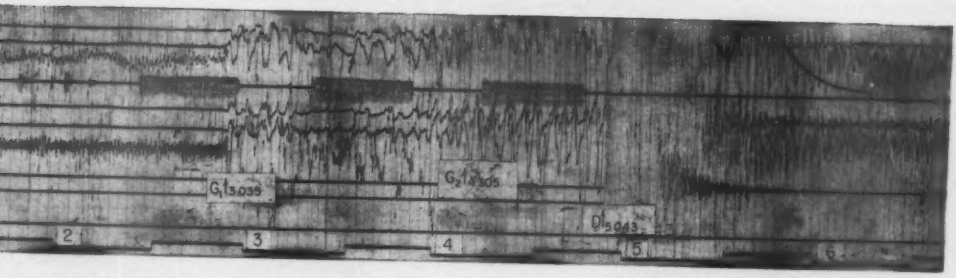

LOW FREQUENCY LOW GAIN
MEDIUM GAIN
HIGH GAIN
RADIO - TIME BREAK
MEDIUM FREQUENCY LOW GAIN
MEDIUM GAIN
HIGH GAIN
HIGH FREQUENCY LOW GAIN
MEDIUM GAIN
HIGH GAIN
CHRONOMETER
TBI + 23
0
1
2

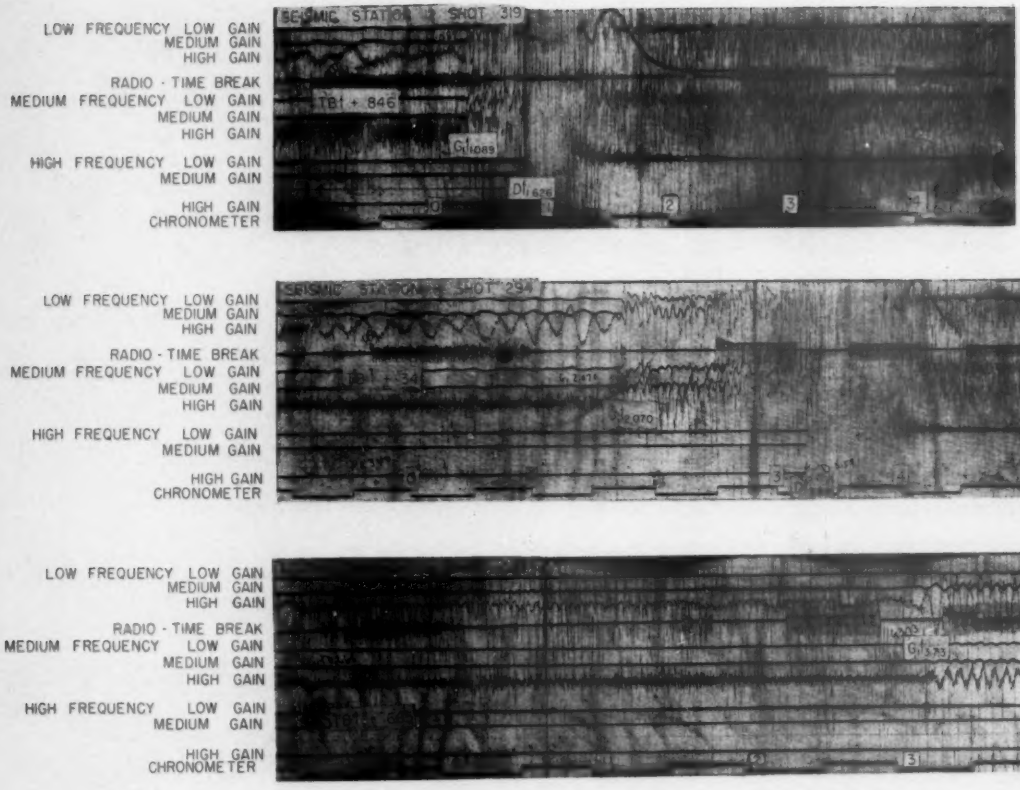
TYPICAL



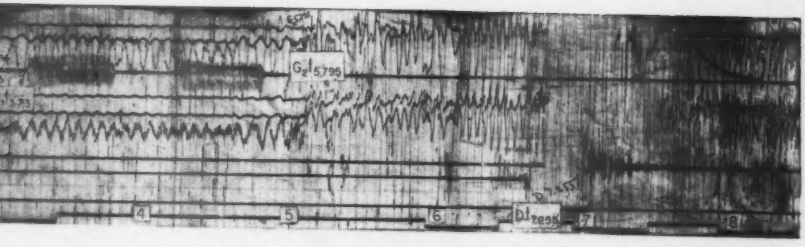




TYPICAL RECORDS



TYPICAL RECORDS



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and is drawn as a masked layer on the CARYN end. An alternative interpretation would admit the possibility of velocity changes along the profile and/or a gradual increase of velocity

Station 18 (*Fig. 8*). Four layers are encountered at this reversed station. Although no arrivals were obtained for the mud layer, its presence is required by the large values of

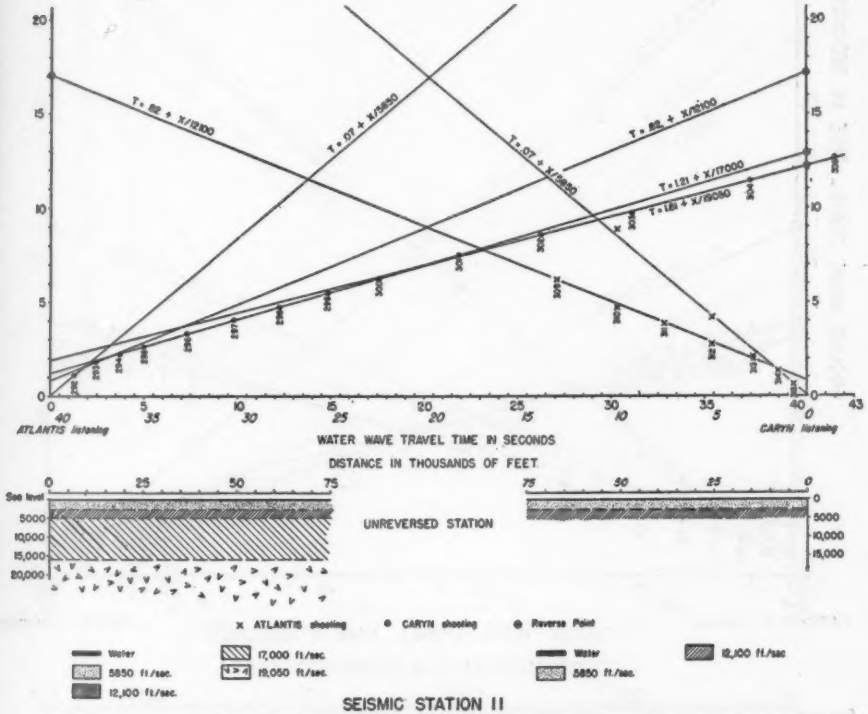
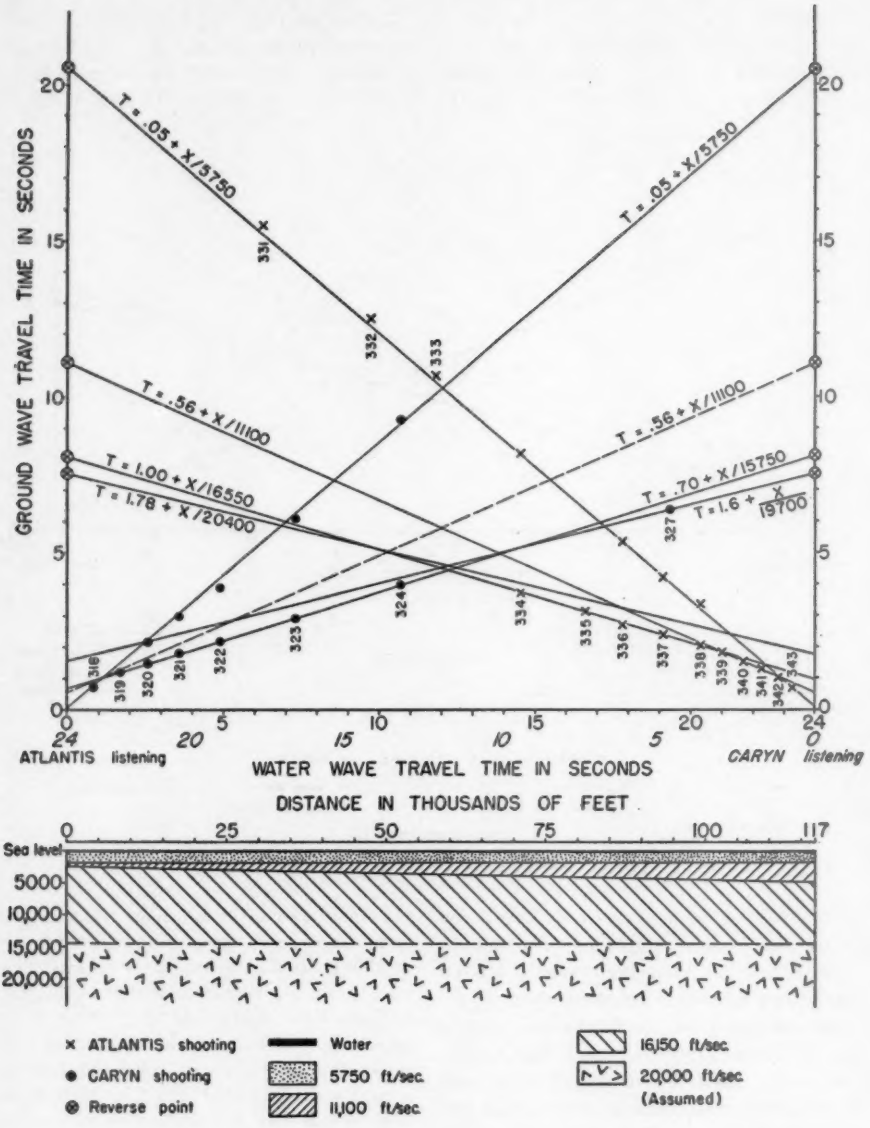


FIGURE 3.—TRAVEL-TIME CURVE, SEISMIC STATION 11

with depth at the ATLANTIS end. The 17,350 ft/sec line is well established. The deepest layer is fixed by three fairly good points on the CARYN line but is not determined for the ATLANTIS line. While the CARYN was shooting for this station, the ATLANTIS drifted 8 miles toward the CARYN. The error due to this drift is relatively small, because of the small dips for the beds above the 21,600 ft/sec layer. The 17,350 ft/sec layer, for example, reverses to better than 0.1 sec. despite the drift and the great distance between the two listening positions. By assuming zero slope, an approximate indication of the depth to the layer with apparent velocity of 21,600 ft/sec is possible.

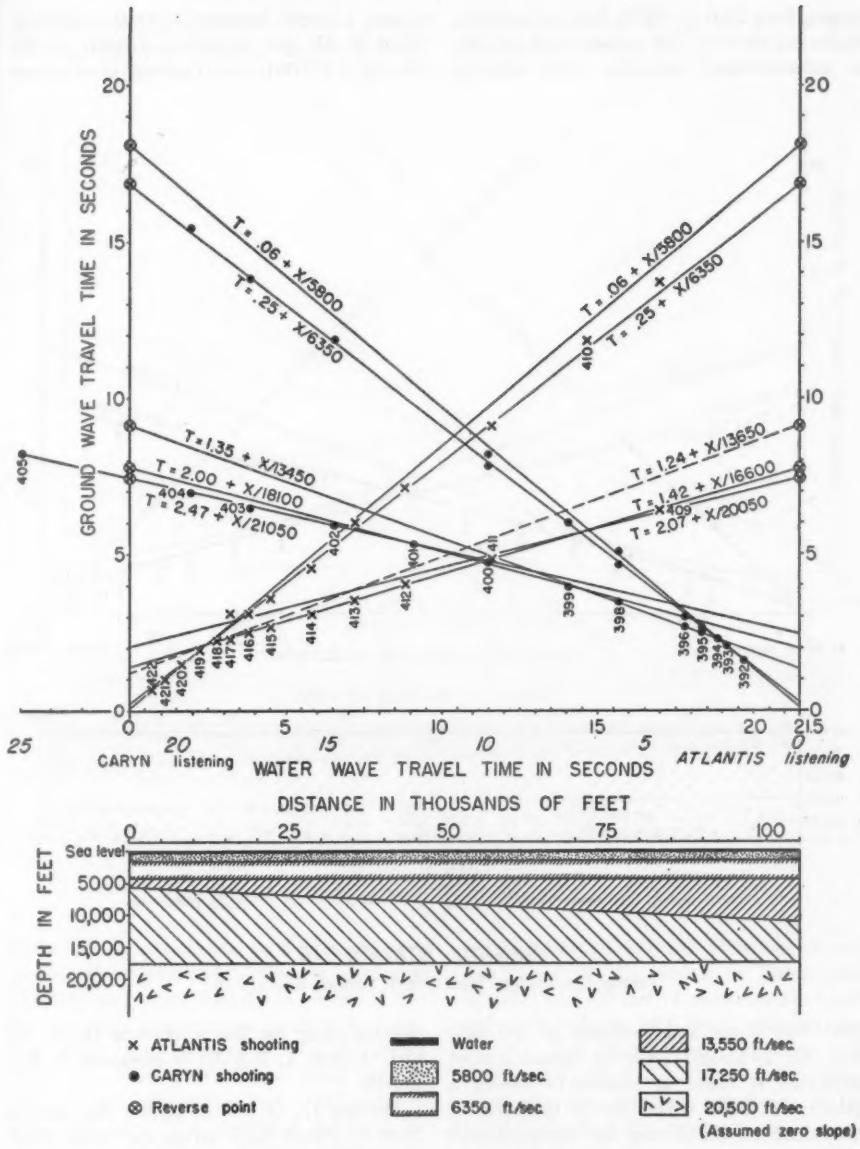
the 9600 ft/sec layer intercepts which do not fit the water depth. Assuming a typical velocity of 5750 ft/sec for the mud-layer velocity, lines were drawn to give intercepts that would agree with the water depth. The 12,450 ft/sec layer, apparently masked at the CARYN end, is drawn through its reverse point and a strong second arrival on shot 496. The 9600 ft/sec layer is well fixed by excellent second arrivals on the ATLANTIS line and first arrivals on the CARYN end. Drifting of the ships might have affected the determination of the 19,950 ft/sec layer, especially in view of the slight separation between shots 488 and 489. However, no forcing is required to match reverse points with the best lines drawn through the points.



SEISMIC STATION 12

FIGURE 4.—TRAVEL-TIME CURVE, SEISMIC STATION 12

Station 19 (*Fig. 9*). Three well-determined, flat-lying layers are indicated in this reversed profile. Owing to a lack of explosives, the lines were not run far enough to obtain data on the deeper layers observed at other stations. Again, drift seems to have negligible effect.



SEISMIC STATION 15

FIGURE 5.—TRAVEL-TIME CURVE, SEISMIC STATION 15

DISCUSSION

Stations 11, 12, and 15 are located on the Grand Banks proper. Station 16 is located in slightly deeper water inshore from the Banks. Although layer thickness varies, the sedimentary section is similar at the four stations

ranging from 2300 to 10,700 feet in thickness, thickening seaward. The surface layer consists of unconsolidated sediments with velocity suggest a deeper basement layer at a depth of about 16,000 feet ± with a velocity in the vicinity of 20,000 ft/sec. A geologic cross section

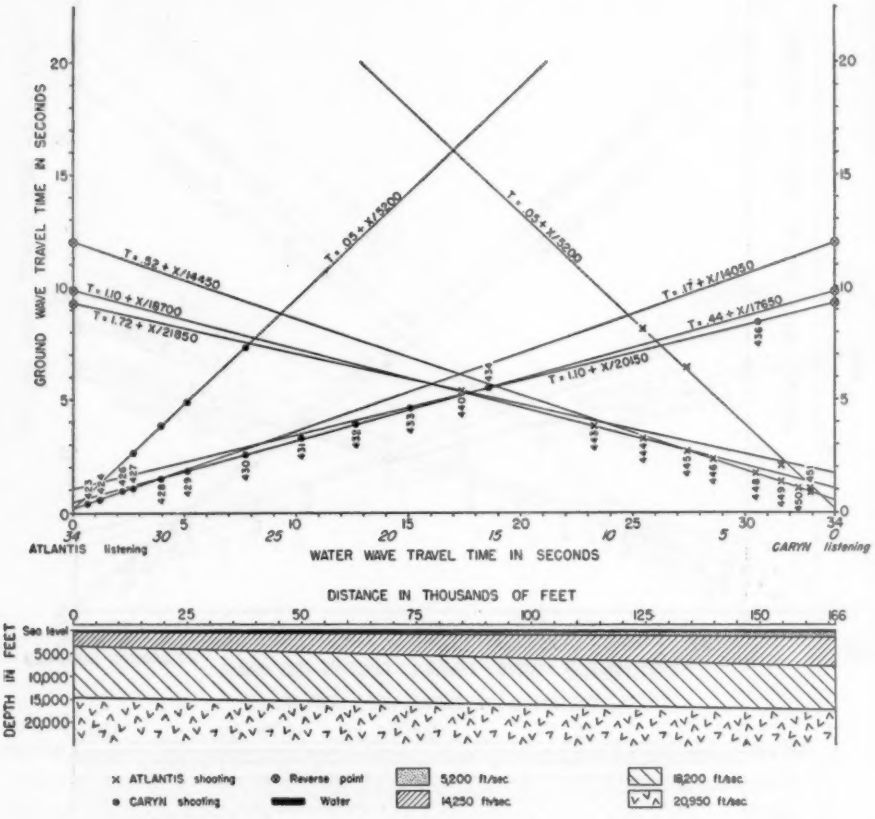
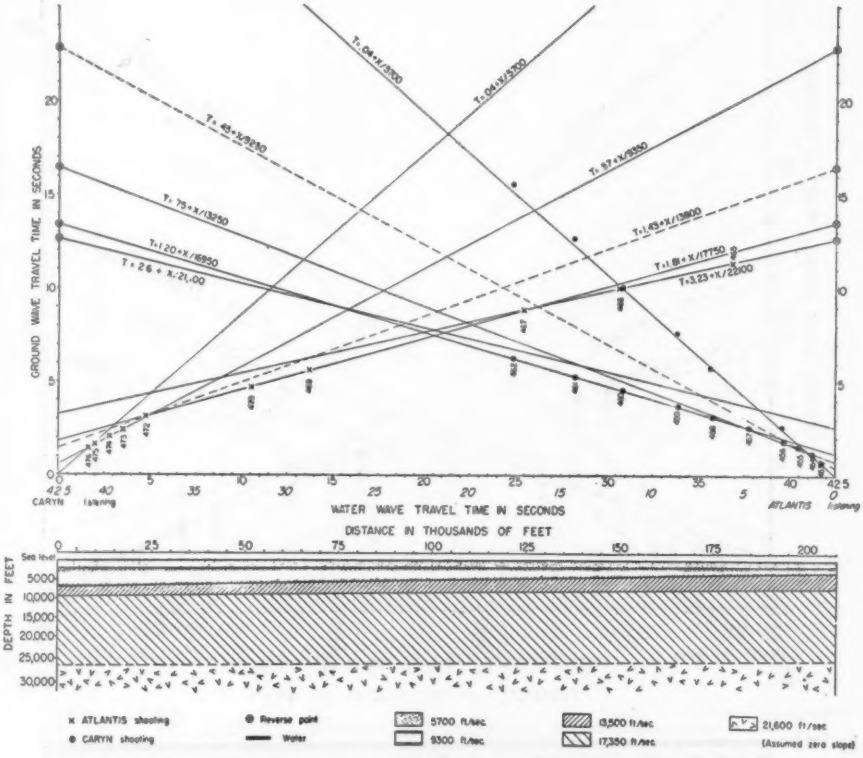


FIGURE 6.—TRAVEL-TIME CURVE, SEISMIC STATION 16

5200–5850 ft/sec and thickness of 100–2400 feet. An additional layer of unconsolidated sediments is found at station 15 having a velocity of 6350 ft/sec and a thickness of 2600–3000 ft. Underlying the unconsolidated layers is a fairly well consolidated sedimentary layer with a velocity range of 11,100–14,250 ft/sec and thickness of 700–6500 feet. The sediments rest on a well-consolidated layer of what is probably crystalline basement with a velocity range of 16,150–18,200 ft/sec. Although quite poorly determined, the data running along the line of stations 16, 11, 12, and 15 (Fig. 1, B-B′-C) is presented in Figure 10.

Stations 17, 18, and 19 form a line running from St. Pierre Bank across the Cabot Strait Trough to Banquereau. Unconsolidated sediments with velocity of 5700 ft/sec and thickness 1400–1800 feet are found on St. Pierre Bank, and 500–1400 feet of similar sediments is inferred for the trough. A semiconsolidated layer is found on St. Pierre Bank and in the trough, having a velocity of 9300–9600 ft/sec

and a thickness range of 1500–5000 feet at both stations. The most striking feature of these cross section across the trough (Fig. 1, A-A′) is presented in Figure 10.



SEISMIC STATION 17

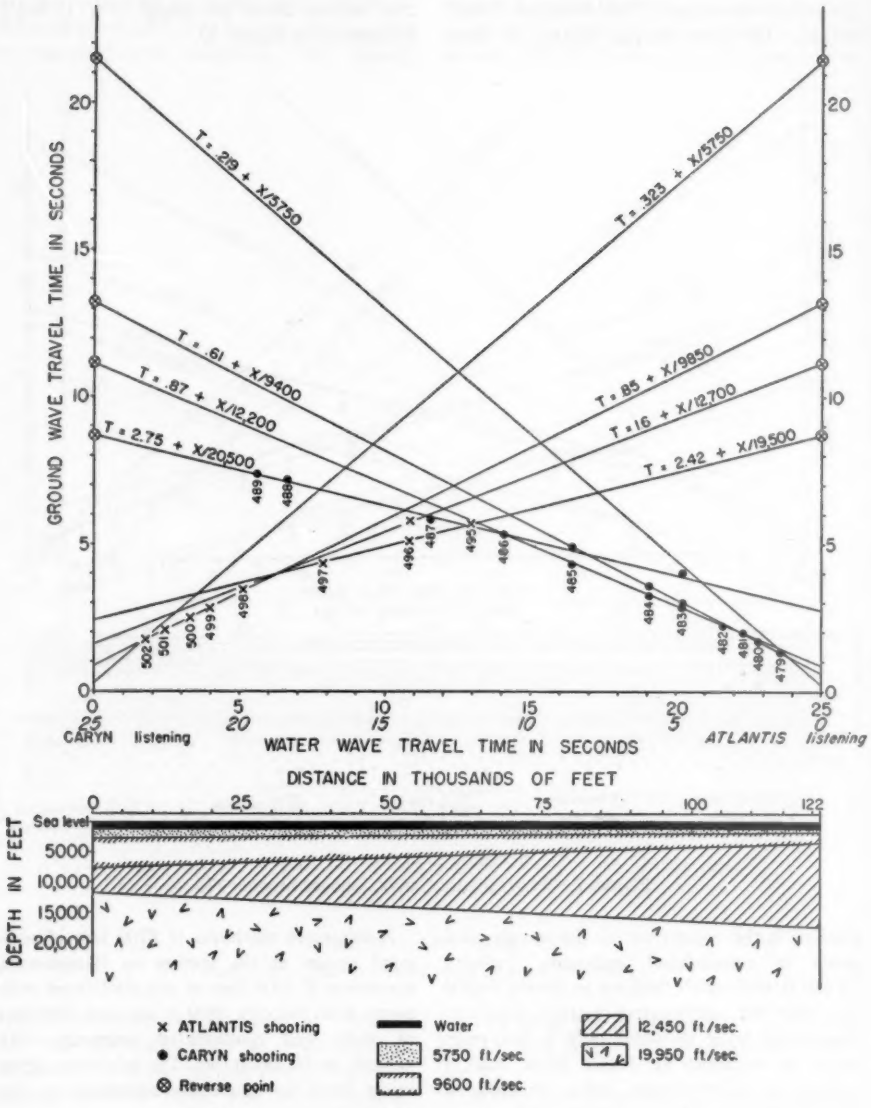
FIGURE 7.—TRAVEL-TIME CURVE, SEISMIC STATION 17

stations is the occurrence, in the trough, of a prism of consolidated sediments (velocity 12,450 ft/sec) which thickens to almost 14,000 feet near the northeastern margin. The corresponding layer is found only a few miles away on adjacent St. Pierre Bank with a velocity of 13,500 ft/sec and a thickness of only 2400 feet. The combined thickness of sediments in the trough reaches a little over 16,000 feet. Basement velocity under the trough is 19,950 ft/sec. Under St. Pierre Bank, basement is found at a higher level with a velocity of 17,350 ft/sec. There is some evidence for a deeper basement layer at a depth of about 27,000 feet under St. Pierre Bank. A geologic

A minimum thickness of 8700 feet of sediment occurs at the station on Banquereau, consisting of 2700 feet of unconsolidated sediments with velocity 5800 ft/sec and 5500 feet of fairly well consolidated sediments with velocity of 10,350 ft/sec. The minimum figure arises from the uncertain correlation of the 15,100 ft/sec layer with the basement.

GEOLOGICAL IMPLICATIONS

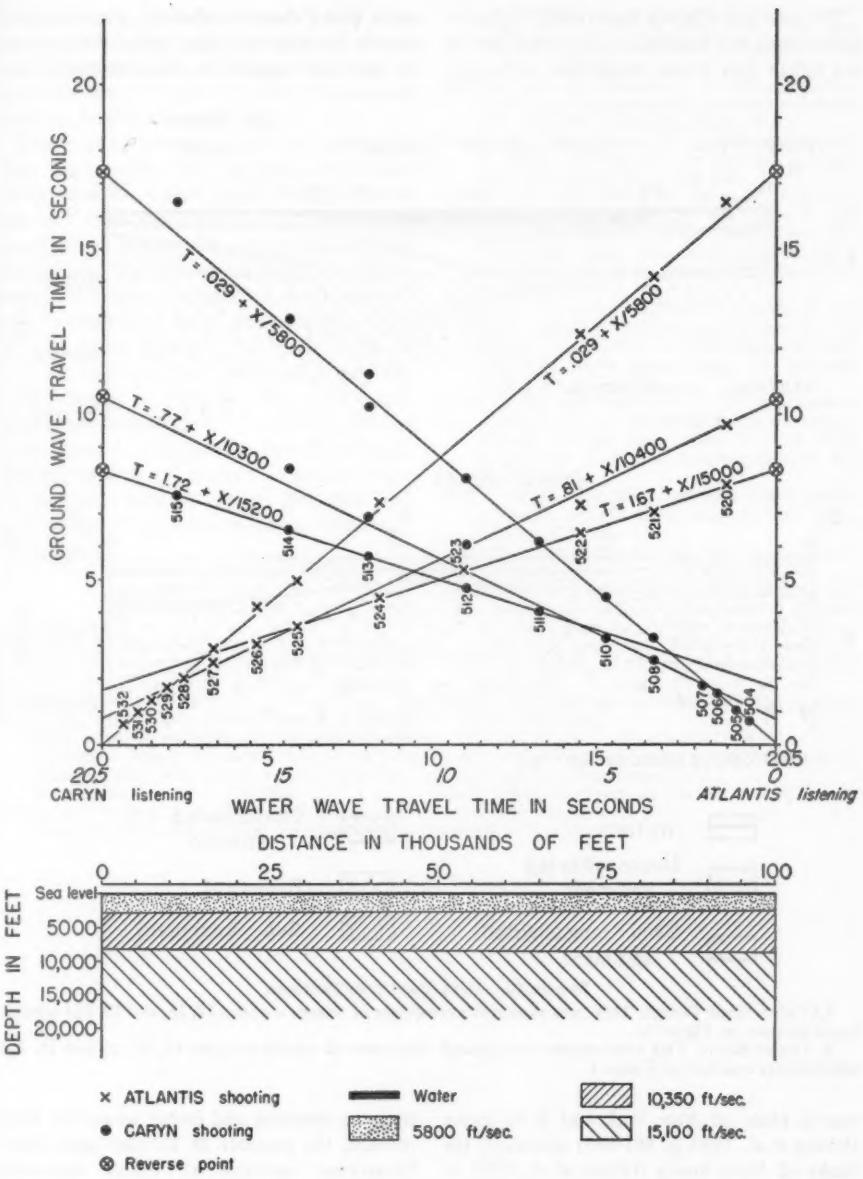
The continental shelf off eastern North America between Cape Hatteras and Labrador may be divided into two physiographic provinces extending north and south of Cape Cod.



SEISMIC STATION 18

FIGURE 8.—TRAVEL-TIME CURVE, SEISMIC STATION 18

North of Cape Cod the topography is irregular, characterized by outer banks and inner deeps. South of Cape Cod the shelf slopes gently seaward. Shepard (1948, p. 107–110) has given a more detailed discussion of bottom topography as well as bottom character.



SEISMIC STATION 19

FIGURE 9.—TRAVEL-TIME CURVE, SEISMIC STATION 19

The sequence of layers found under the outer banks south and southeast of Newfoundland is not unlike that traced under the submerged coastal plain off New York and New Jersey (Ewing *et al.*, 1950, p. 881–889) and under the banks off Nova Scotia (Officer *et al.*, 1953, in press). In the earlier work, and in later investigations off Long Island by Oliver and Drake (1951, p. 1294–1295), the unconsolidated layer is related to upper Cretaceous, Tertiary, and Quaternary sediments. The more consolidated layer is related to pre-Upper Cretaceous, post-Paleozoic sediments. Correlation of seismic layering over such great distances is at best only suggestive. However, recent reports on dredging and coring operations have revealed the presence of Tertiary and Upper Cretaceous outcrops at widely separated points on the continental slope off the eastern United States (Stetson, 1949, p. 8–13; Northrop and Heezen, 1951, p. 397; Ericson *et al.*, 1952, p. 500); these and the seismic results support the hypothesis that the shelf off eastern North America is a depositional

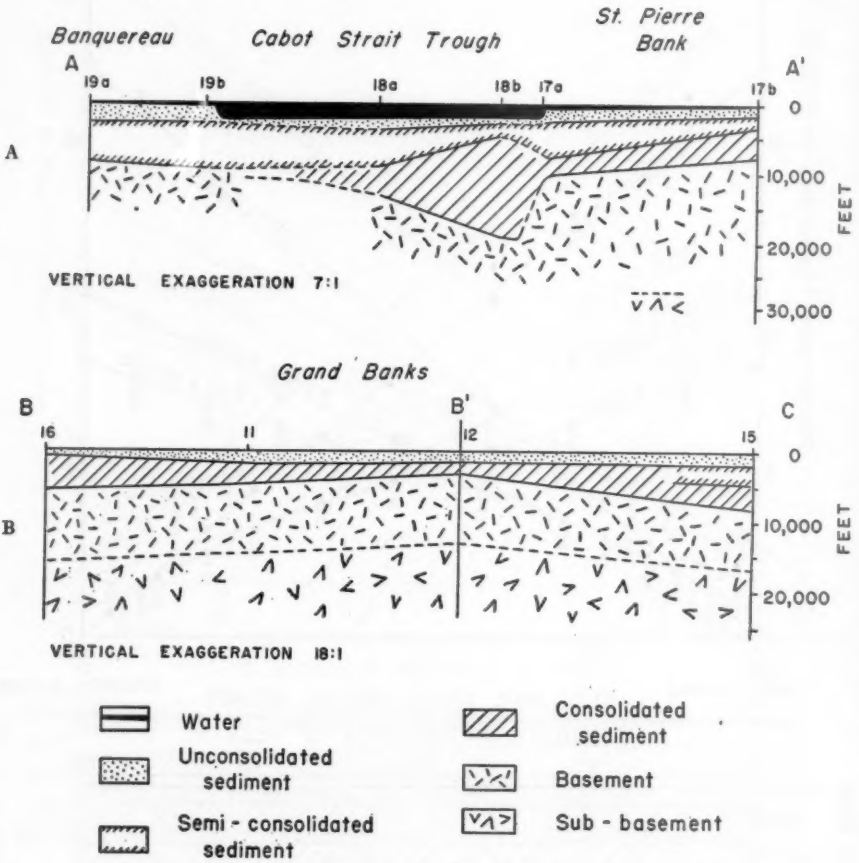


FIGURE 10.—GEOLOGIC CROSS SECTIONS

A. Cabot Strait Trough. This cross section is a composite of seismic stations 17, 18, and 19. For approximate location *see* Figure 1.

B. Grand Banks. This cross section is a general composite of seismic stations 11, 12, 15 and 16. For approximate location *see* Figure 1.

feature dating back to at least Lower Cretaceous time. The physiographic differences north and south of Cape Cod are believed to be primarily due to relatively recent erosion and, possibly, to glacial deposition.

The seismic results confirm the conclusion (*see*, for example, Tectonic map of Canada, 1950) that the Cabot Strait Trough leading outward from the Gulf of St. Lawrence is structural in origin, the northeastern margin having been downfaulted as much as 2 miles during the time of deposition of the consolidated sedimentary layer. Earthquake activity (Gutenberg and Richter, 1949, p. 81) indicates that the fault may be mildly active yet. The recent tremor of June 27, 1951 (U.S.C.G.S. preliminary epicenter 45°N. 57°W.) occurred in the Trough not far from station 18. Although geophysical evidence favors a structural origin for the Cabot Straight Trough, glaciation may have modified its form somewhat (Shepard, 1931, p. 863).

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